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REPORT

SOLID POLYMER ELECTROLYTE (SPE)
FUEL CELL TECHNOLOGY PROGRAM

FINAL REPORT (PHASE 1/1A)

Contract NAS 9-14345, DRL Line Item No. 4

Prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

DIRECT ENERGY CONVERSION PROGRAMS
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GENERAL ELECTRIC

REPRODUCED BY
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ACKNOWLEDGEMENTS

This report summarizes the results of a solid polymer electrolyte fuel cell technology program conducted for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, by the General Electric Company, Direct Energy Conversion Programs, Wilmington, Massachusetts, under Contract NAS 9-14345. The period of performance was August 1974 through August 1975.

This work was performed under the guidance of Mr. G. D. Hydrick, Jr., Program Manager for the Power and Propulsion Branch of NASA/Lyndon B. Johnson Space Center. The overall program was directed by Mr. J. F. McElroy, Project Engineer, General Electric Company, Direct Energy Conversion Programs.

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1.0 SUMMARY

The primary objective of this contract was to evaluate several facets of the solid polymer electrolyte fuel cell which showed promise of improving the characteristics of the technology. The major target areas were:

- Reduced Fuel Cell Costs
- Reduced Fuel Cell Weight
- Improved Fuel Cell Efficiency
- Increased Systems Compatibility

The secondary objective was to incorporate demonstrated advances into a full scale hardware design and to fabricate a single cell unit to this design.

A substantial degree of success was demonstrated in each of primary target areas as follows:

- Reduced Costs
  - Thinner membrane
  - New low cost membrane
  - Commercially available wetproofing
  - Elimination of gold
  - Elimination of fuel side screens
  - Non-platinized membrane
  - Bipolar current collection
- Reduced Weight
  - Thinner membrane
  - Elimination of fuel side screens
  - Bipolar current collection
- Improved Efficiency
  - Higher pressures
  - Bipolar current collection
  - Thinner membrane
- Increase System Compatibility
  - Operation on contaminated reactants
  - Higher temperature waste heat

The significance of the program evaluations is summarized on Table I and Figure 1.

The secondary objective was satisfied with the completion of the design and the fabrication and checkout of full scale fuel cell stack NT-1 (see Figure 2).

Table I

Solid Polymer Electrolyte
Fuel Cell Technology Evaluations

DEMONSTRATED ADVANCES

- Tolerance to Contaminated Reactants
  (up to 80% N_2 - 25% CO_2 - 0.3% CO Demonstrated)
- Thinner Low Resistance Electrolyte
  ($25/Ft^2 vs $35/Ft^2 and 2% increase efficiency at 200 ASF)
  (2.7 cents/cm^2 vs 3.8 cents/cm^2 and 2% increase efficiency at .21 amps/cm^2)
- Elimination of Anode Distribution Screens
  ($25/Ft^2)
  (2.7 cents/cm^2)
- Low Cost Cathode Wetproofing
  ($2/Ft^2 vs $35/Ft^2)
  (0.2 cents/cm^2 vs 3.8 cents/cm^2)
- Low Cost Cathode Screen (BiPolar)
  ($5/Ft^2 vs. $100/Ft^2)
  (0.5 cents/cm^2 vs 10.8 cents/cm^2)
- Simplified Membrane Processing
  ($10/Ft^2 vs $20/Ft^2)
  (1.0 cents/cm^2 vs 2.1 cents/cm^2)

PROMISING AREAS FOR ADVANCEMENT

- Low Cost Electrolyte
  ($10/Ft^2 vs $35/Ft^2)
  (1.0 cents/cm^2 vs. 3.8 cents/cm^2)
- High Temperature Operation (300°F) (149°C)
  (Decreased Radiator Size and Cost)

POTENTIAL AREAS FOR ADVANCEMENT

- High Acid Content Electrolyte
  (2% Efficiency Increase Goal)
- Weight Reduction in Catalyst Noble Metal
  ($50/Ft^2 Reduction Goal)
  (5.4 cents/cm^2 Reduction Goal)
- High Porosity Wetproofing
  (1% Efficiency Increase Goal)
- Reduced Cost Separator Materials
  ($20/Ft^2 Reduction Goal)
  (2.1 cents/cm^2 Reduction Goal)

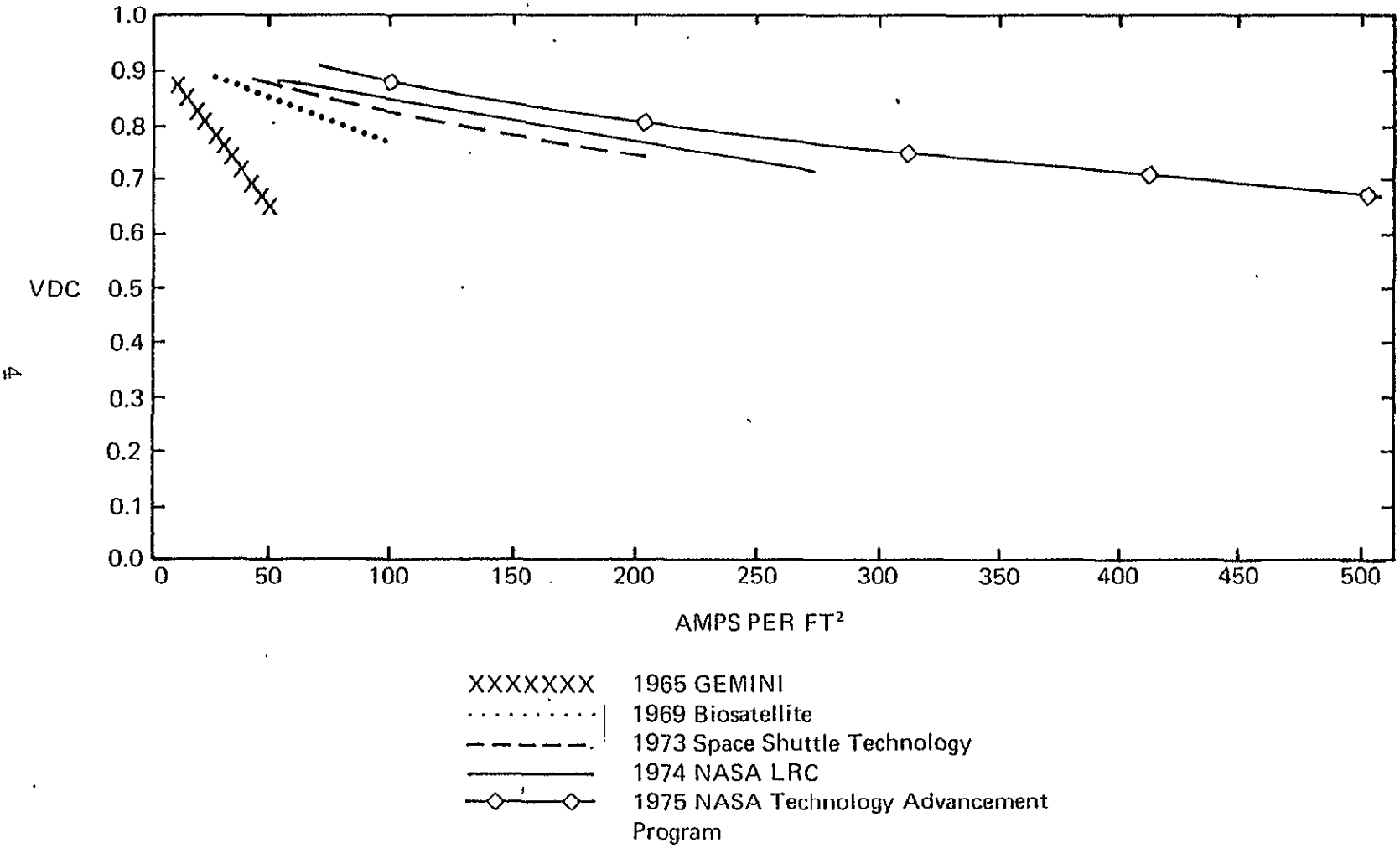

Figure 1. Solid Polymer Electrolyte Fuel Cell Performance

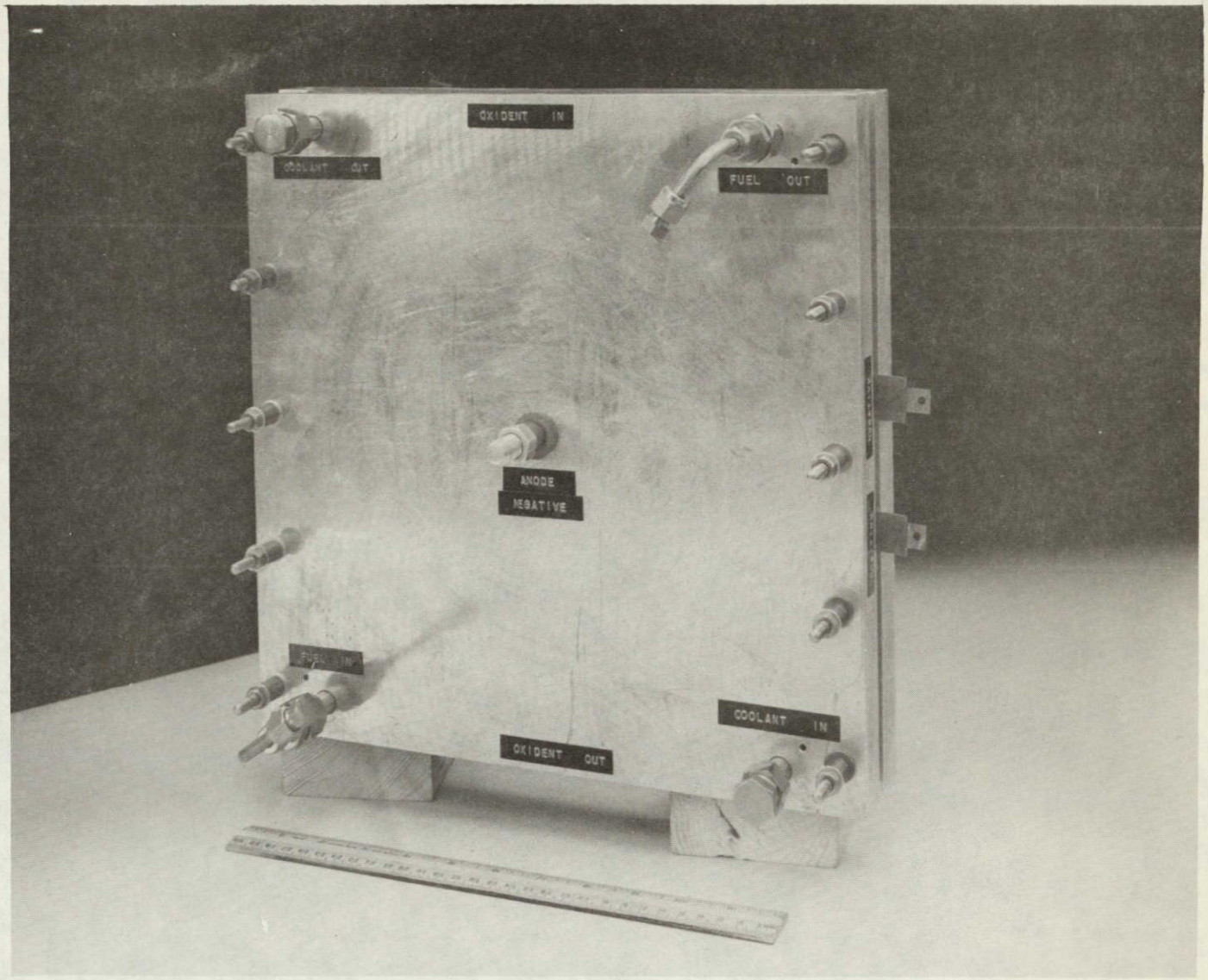

Figure 2. **Fuel Cell Assembly NT-1**

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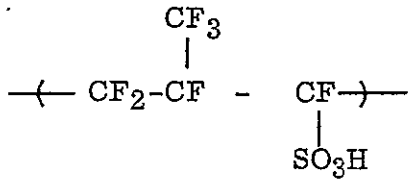
2.0 TECHNICAL BACKGROUND

2.1 General Background

The SPE fuel cell technology was first developed into a viable product in 1960. Over the past 15 years, improvements in both the SPE and the electrode technologies resulted in an increased field of applications to include electrolysis systems, oxygen concentrators and regenerative fuel cells. All four electrochemical devices utilize the same basic SPE and electrode components. Thus, the experience gained from one application can be used in the further improvement of the other devices.

The heart of these devices is the SPE which is approximately a 10 mil thick plastic film fabricated from ion exchange material. This currently utilized material has a structure as follows:



This is essentially a sulfonated analog of Teflon with physical properties very similar to Teflon.

The use of the SPE as the sole electrolyte in an electrochemical system offers the following advantages:

- Minimum weight
- Immobile and invariant during life
- Minimum volume
- Ease of handling during assembly
- Capability of handling high pressure differentials across the membrane
- No tendency to react with CO_2 to form carbonates

2.1.1 Solid Polymer Electrolyte Technology

The Nafion (R) SPE described above is a product of duPont and has been utilized extensively by GE/DECP in electrochemical applications since 1968. This membrane is extremely stable, both physically and chemically, while exhibiting excellent physical and electrochemical properties. These properties are listed below:

Property	Value
Tensile	> 2500 psi (> 17,235 kN/m^2)
Elongation	>120%
Burst Strength, unsupported	>100 psig (> 689 kN/m^2 gauge)
Water Content	25-40 Weight %
Resistivity	< 15 ohm-cm
Life in Electrochemical System (hours)	> 34,000 hours demonstrated to date in fuel cells
Thermal Stability	> 300°F (> 149°C)

The Nafion (R) SPE is the latest in a series of GE/DECP membrane systems that included phenol-formaldehyde sulfonic, polystyrene sulfonic, and trifluorostyrene sulfonic acids. The Nafion (R) SPE was the only membrane that offered the excellent combination of physical and chemical stability required in the electrochemical environments.

The first Nafion (R) SPE's tended to degrade slowly in an electrochemical environment as evidenced by a slow generation of HF and CO_2 from the operating device. However, this problem has been rigorously researched by both duPont and GE/DECP and has culminated in a stack (four cells) of 0.38 ft^2 (354 cm^2) (AFC 6) fuel cells that has been operating over 34,000 hours with no detectable degradation products (HF). The performance characteristic over its life to date is shown in Figure 3. It is operating at 70 psia (483 kN/m^2) oxygen-side pressure and for the last 31,000 hours has been run at 180°F with current densities up to 260 ASF .28 amps/cm^2).

2.1.2 Electrode Technology

The GE/DECP electrode structures are thin catalyst layers pressed onto the SPE surface. The catalyst/SPE electrode also contains a thin (3-4 mil) (.0762-.1016 mm current collector screen, and in order to prevent water masking of the fuel cell oxygen electrode where product water is formed, a wetproofing film is placed on top of the catalyst/current collector. The performance of these electrode structures has been invariant for over 34,000 hours with no evidence of performance decay.

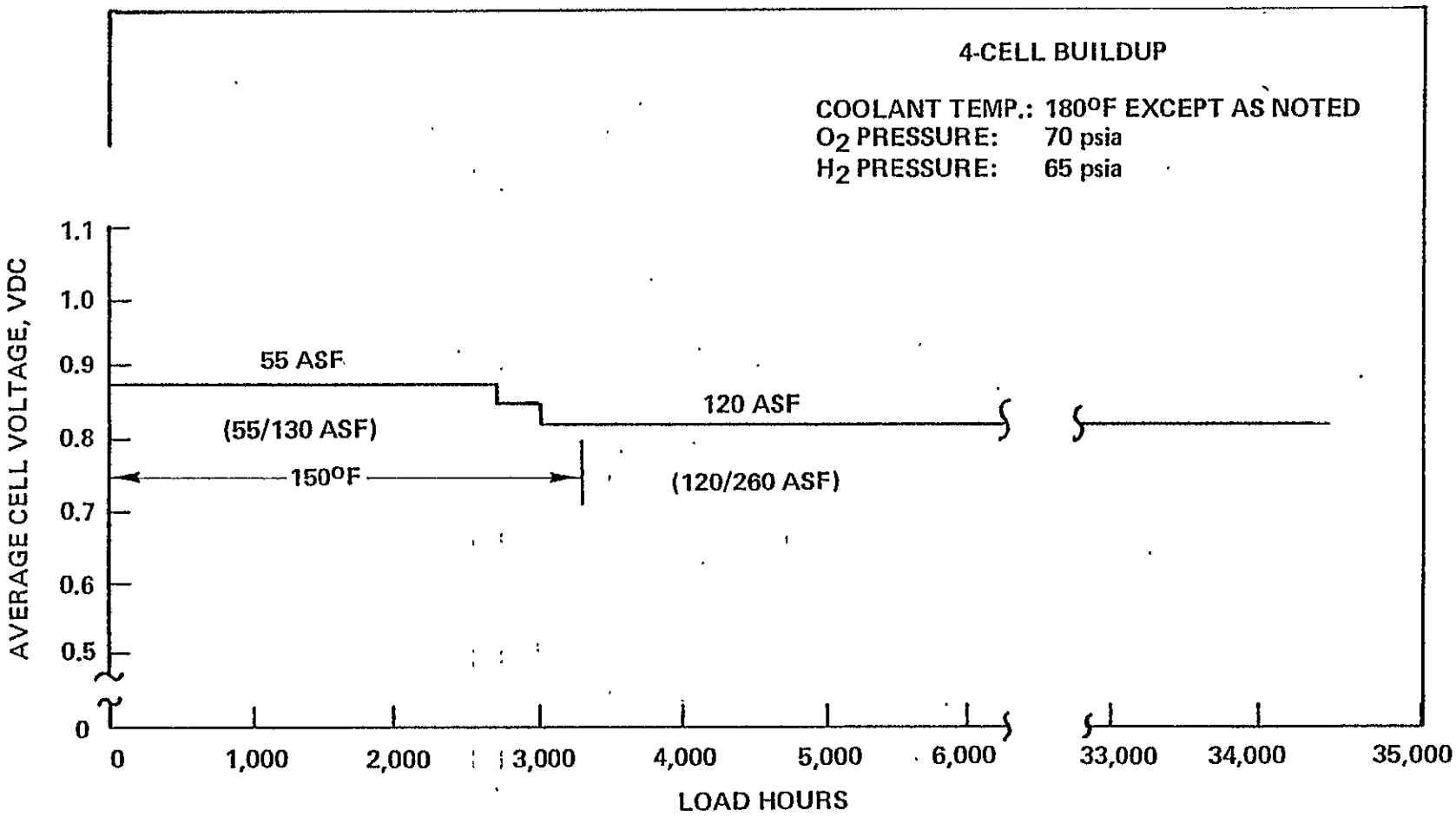


Figure 3. Fuel Cell Buildup (AFC 6) Life Test Performance History

2.2 Major Fuel Cell Programs

The Gemini spacecraft program marked the first operational use of an SPE unit. The General Electric solid polymer electrolyte fuel cells used on that program successfully completed all seven spacecraft missions, accumulating a total of 850 hours (5000 stack-hours) of flight operation with an excellent record of performance and reliability. The spacecraft system included two 1-KW modules, each containing three 32-cell stacks.

A total of 250 stacks of the production configuration were built during the Gemini program. Most of these were used for reliability, endurance, and overstress testing and accumulated more than 80,000 stack-hours of operating experience in addition to flight operation.

A second-generation model of this fuel cell design successfully operated in orbit continuously for over 40 days (planned mission of 30 days) on Biosatellite Spacecraft 501 and stopped functioning only when the reactants were depleted.

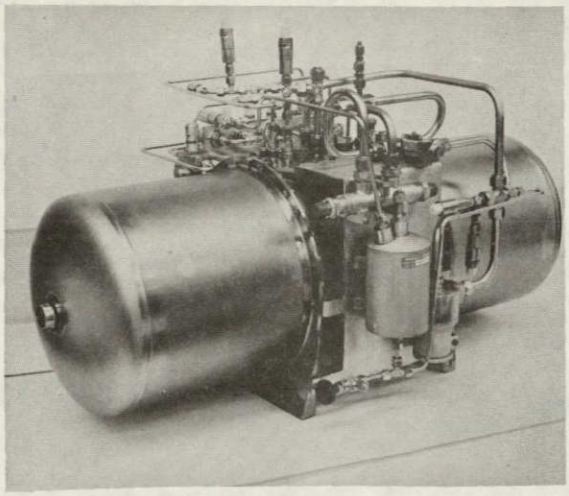
The so-called "back-to-back" cell design concept, where cathodes of adjacent cells faced each other, was initially developed for Air Force satellites. This concept was continued under NASA's sponsorship.

In this NASA Space Shuttle Technology Development Program, General Electric fabricated and evaluated flightweight fuel cell hardware. Noteworthy is the fact that a 3-cell assembly completed over 6500 hours of life testing, a 38-cell stack accumulated 5000 hours, and a 32-cell stack with ancillary components in a prototype flight configuration achieved 2000 hours of operation.

The technology developed during the Space Shuttle technology has recently been repackaged as a 3 KW fuel cell for the Navy's High Altitude Super-Pressurized Powered Aerostat (HASPA).

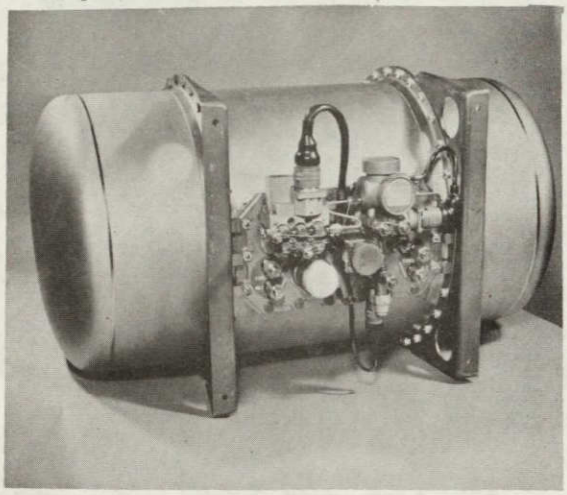
Recently under sponsorship of NASA's Lewis Research Center, initial development of a new SPE concept was started. The major feature of this concept was the removal of product water via a dynamic recycling oxygen system as opposed to the traditional wick and separator approach used since the Gemini Program. The advantages of this concept are in the areas of weight, cost and efficiency.

Figures 4 thru 6 display the various products described above. Figure 7 is a graphical presentation of the past fifteen years of progress in the SPE fuel cell technology.



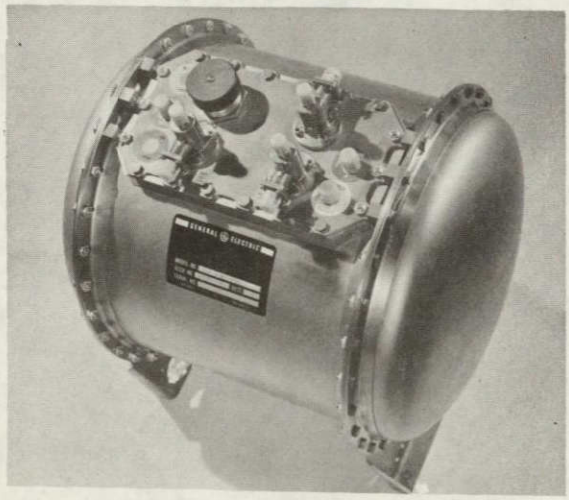
SPACE SHUTTLE FUEL CELL PROTOTYPE

- 5000 HOURS LIFE TEST - 2.5 KW STACK
- 2000 HOURS LIFE TEST - 2.5 KW MODULE



GEMINI FUEL CELL

- FIRST FUEL CELL SYSTEM IN SPACE
- SEVEN SUCCESSFUL MANNED SPACE FLIGHTS



BIOSATELLITE FUEL CELL

- OPERATED 40 DAYS IN SPACE
- FIRST APPLICATION OF FLUOROCARBON SPE

Figure 4.

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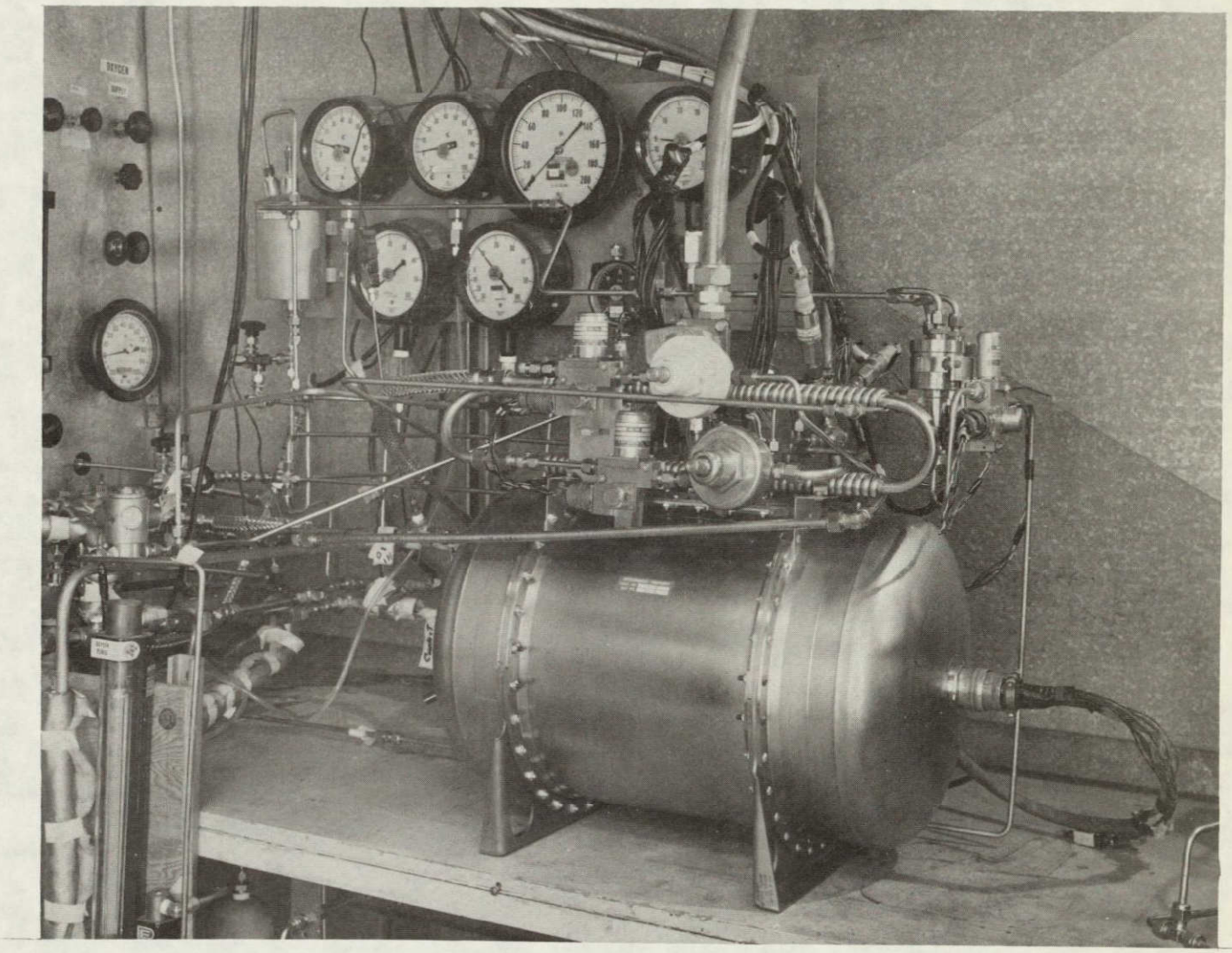

Fuel Cell Module FS-2 (3KW)

A Modified Version of the solid Polymer Electrolyte Fuel Cell developed by General Electric Company for NASA/JSC is presently being utilized by the U. S. Navy as part of their High Altitude Powered Balloon Program. The Fuel Cell provides power for propulsion and housekeeping for one week missions.

Figure 5.

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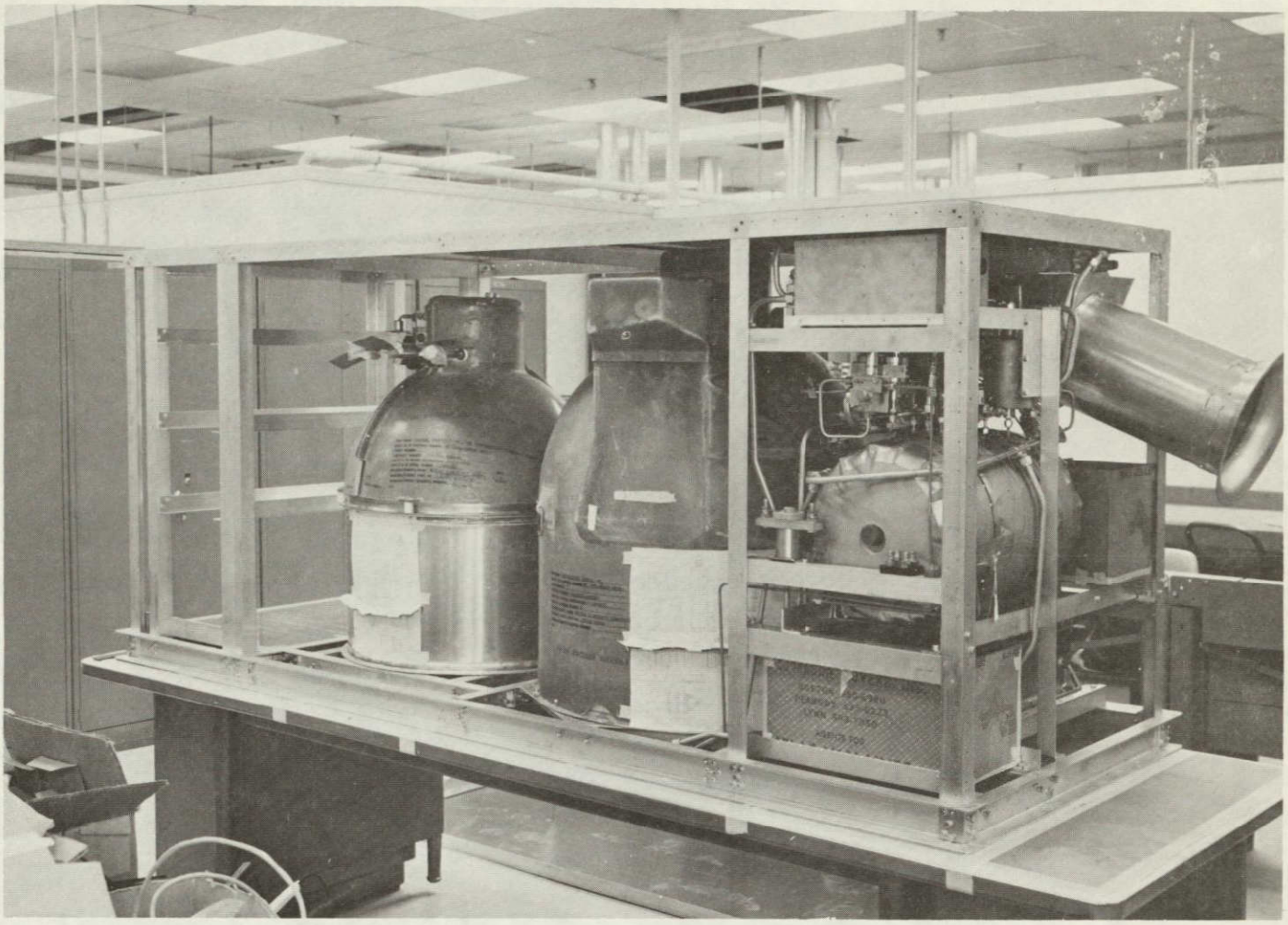

Complete Fuel Cell Power System, Including Cryogenic Tasks, in the Process of Assembly for U. S. Navy Balloon Program.

The Fuel Cell Performance Remains at Specification Levels Following 1000 Hours Operation and 2 Years Storage.

Figure 6.

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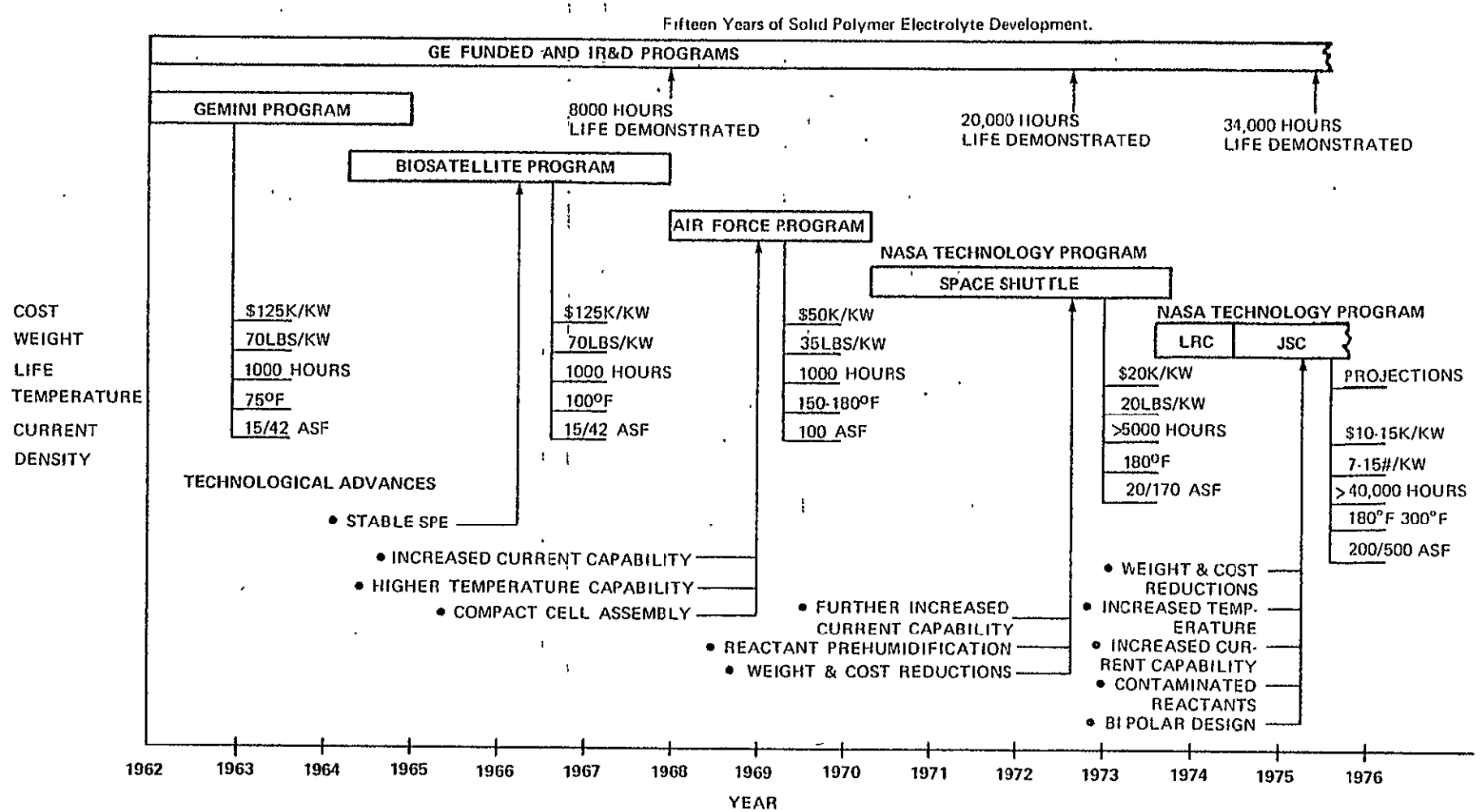


Figure 7. Progress of SPE Space Fuel Cell Technology

3.0 TECHNOLOGY ACTIVITIES

The major tasks of this program were twofold. The first task was to evaluate several promising aspects of the solid polymer electrolyte fuel cell in laboratory-sized hardware. The second major task was to incorporate demonstrated advances into a full scale design and to fabricate and check out this design in a single cell stack.

3.1 Subscale Laboratory Evaluations

This major task was subdivided into twelve subtasks as follows:

1) Anode Catalyst Performance
2) SPE Membrane Performance
3) Cathode Catalyst Performance
4) Wetproofing Performance
5) Catalyst Loading Reductions
6) Baseline Performance Characteristics
7) Medium Pressure Range Operation
8) Non-Platinized Membrane Evaluation
9) Catalyst Mix Optimization
10) Cathode Wetproofing
11) Electrode Manufacturing Techniques
12) Extended Endurance Testing

In order to determine the performance of a standard cell, a baseline configuration was established utilizing the 1974 current state-of-the-art. This 1974 baseline consisted of:

- Solid Polymer Electrolyte
  - duPont's Nafion (R)
  - 10 mil (.2540 mm) thick
  - 35-40% H_2O
  - 1200 equivalent weight
  - Platinized
- Anode Electrode
  - 4 grams/ft^2 (4.3 mg/cm^2)
  - 12.5% T-30
  - 87.5% Pt black

- Cathode Electrode
  - 4 grams/ft^2 (4.3 mg/cm^2)
  - 12.5% T-30
  - 87.5% Pt black
  - 1/4 inch (6.35 mm) stand pipe
  - 3 mil (.0762 mm) gold screen
- Current Collection
  - BiPolar
  - Multiple gold screen anode gap
  - Open cathode gap

The baseline configuration was sized to fit the laboratory 3 x 3 inch hardware shown on Figure 8. The baseline cell performance was determined when operating on oxygen/hydrogen, air/hydrogen, and oxygen/contaminated hydrogen. These performance results are displayed on Figure 9. The performance displayed on Figure 9 will be utilized throughout this report to be compared with the performances of the new configuration variations.

3.1.1 Anode Catalyst Performance

The purpose of this subtask was to evaluate the solid polymer electrolyte fuel cell performance capabilities utilizing fuel contaminated with significant amounts of CO_2 and CO. Three fuel mixtures were selected for evaluation as they represented typical effluents from chemical fuel processing plants. The volumetric proportions of these mixtures were:

Mixture #1	25% CO_2
	0.3% CH_4
	10 PPM CO
	Balance H_2
Mixture #2	25% CO_2
	0.1% CH_4
	0.3% CO
	Balance H_2
Mixture #3	25% CO_2
	42% N_2
	Balance H_2

The major problem anticipated was the catalyst poisoning effect by the relatively small amounts of carbon monoxide in mixtures #1 and #2.

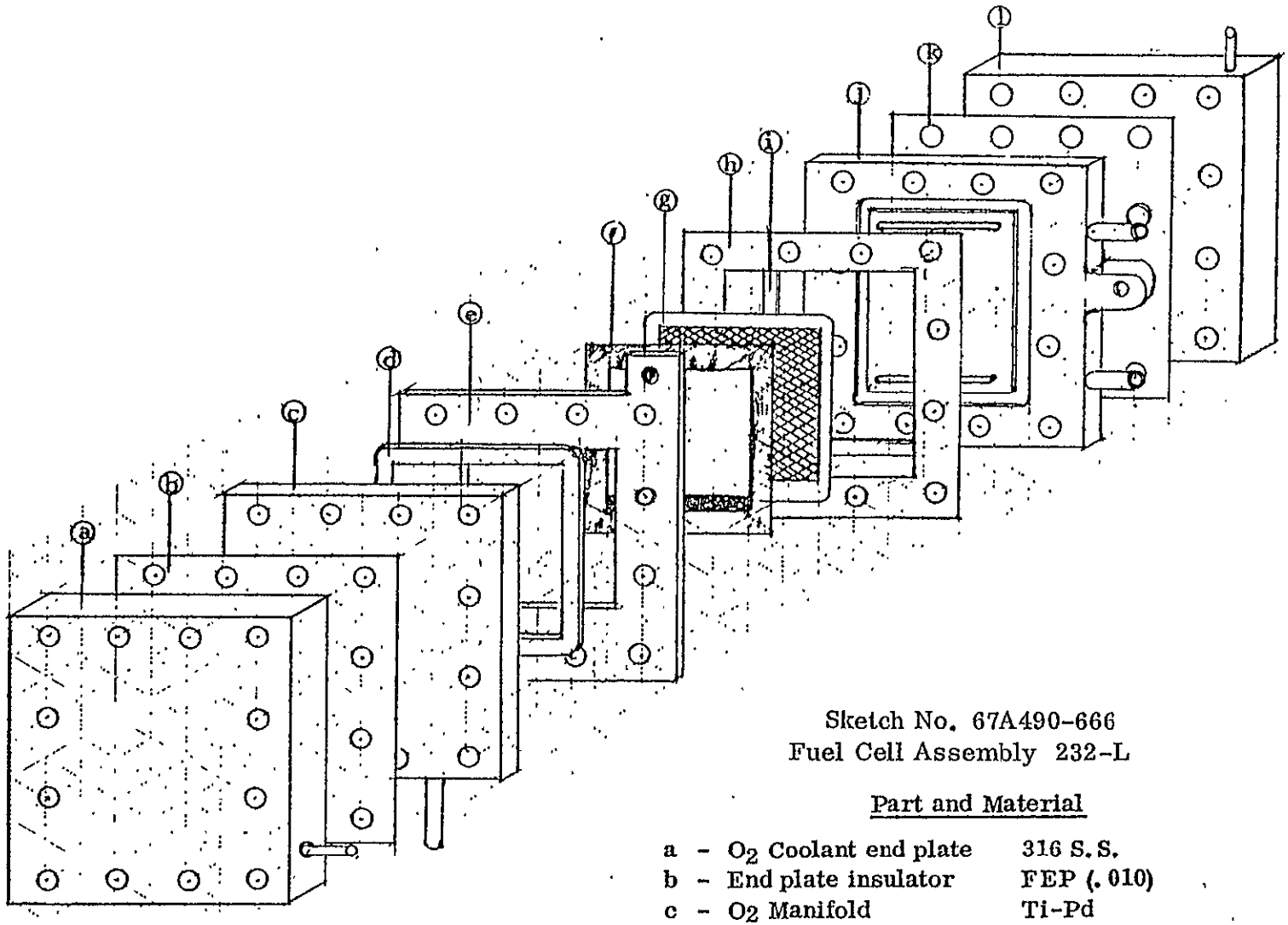
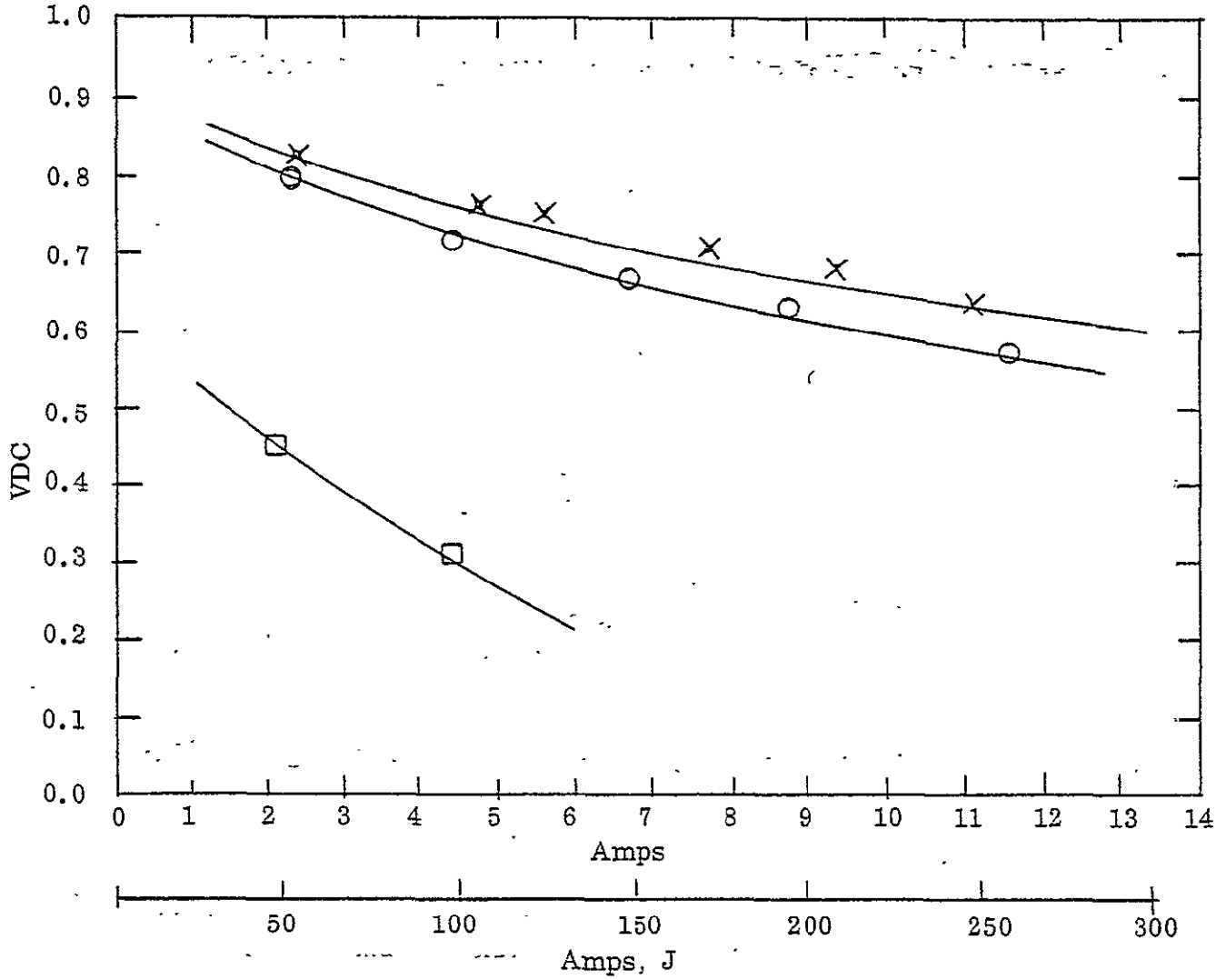


Figure 8. Laboratory 3 x 3 Inch Fuel Cell Hardware

Sketch No. 67A490-666
Fuel Cell Assembly 232-L

Part and Material		
a	– O_2 Coolant end plate	316 S.S.
b	– End plate insulator	FEP (.010)
c	– O_2 Manifold	Ti-Pd
d	– Cathode gasket	Silicone Rubber (.060)
e	– O_2 Collector	Ti-Pd
f	– M and E	"R" SPE/4 mg/cm^2 Pt Electrodes
g	– Anode diffuser screen	Gold
h	– Collector insulator	FEP (.005)
i	– Anode gasket	Silicone Rubber (.060)
j	– H_2 Manifold collector	Ti-Pd
k	– End plate insulator	FEP (.010)
l	– H_2 Coolant end plate	316 S.S.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

X - O_2/H_2 (120°F) R = 0.0135 ohm

O - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

□ - O_2/H_2 (25% CO_2 - 0.3% CO - 0.1% CH_4) at 1.25 stoich (165°F) R = 0.016 ohm

Figure 9. Baseline Fuel Cell Performance

The approach taken to minimize the poisoning effect of the CO was to incorporate various anode catalyst alloys which were reported to have higher tolerance to CO contaminated fuel than pure platinum black. The literature search identified four metals which had promise of performing well on contaminated fuel containing CO when these metals were alloyed with platinum black. These were Ir, Rh, Ru and various oxide levels of tungsten.

A total of nine cells were fabricated to the baseline (1974) configuration except for variations in the anode materials. The total metal loading of the anode, however, was maintained at the baseline weight. Table II displays a brief description of each cell configuration and a numerical comparison of O_2/H_2 and air/H_2 performance with the 1974 baseline cell.

The first four cells tested utilized various amounts of either Ir, Rh or Ru mixed with the anode platinum. The resultant performances were below anticipated, especially on the fuel containing 0.3% CO. Figure 10 displays cell NT-1-4 which was the best of the first four cells. Note that although the contaminated fuel (0.3% CO) performance was considerably better than baseline, a major loss from pure H_2 performance was observed.

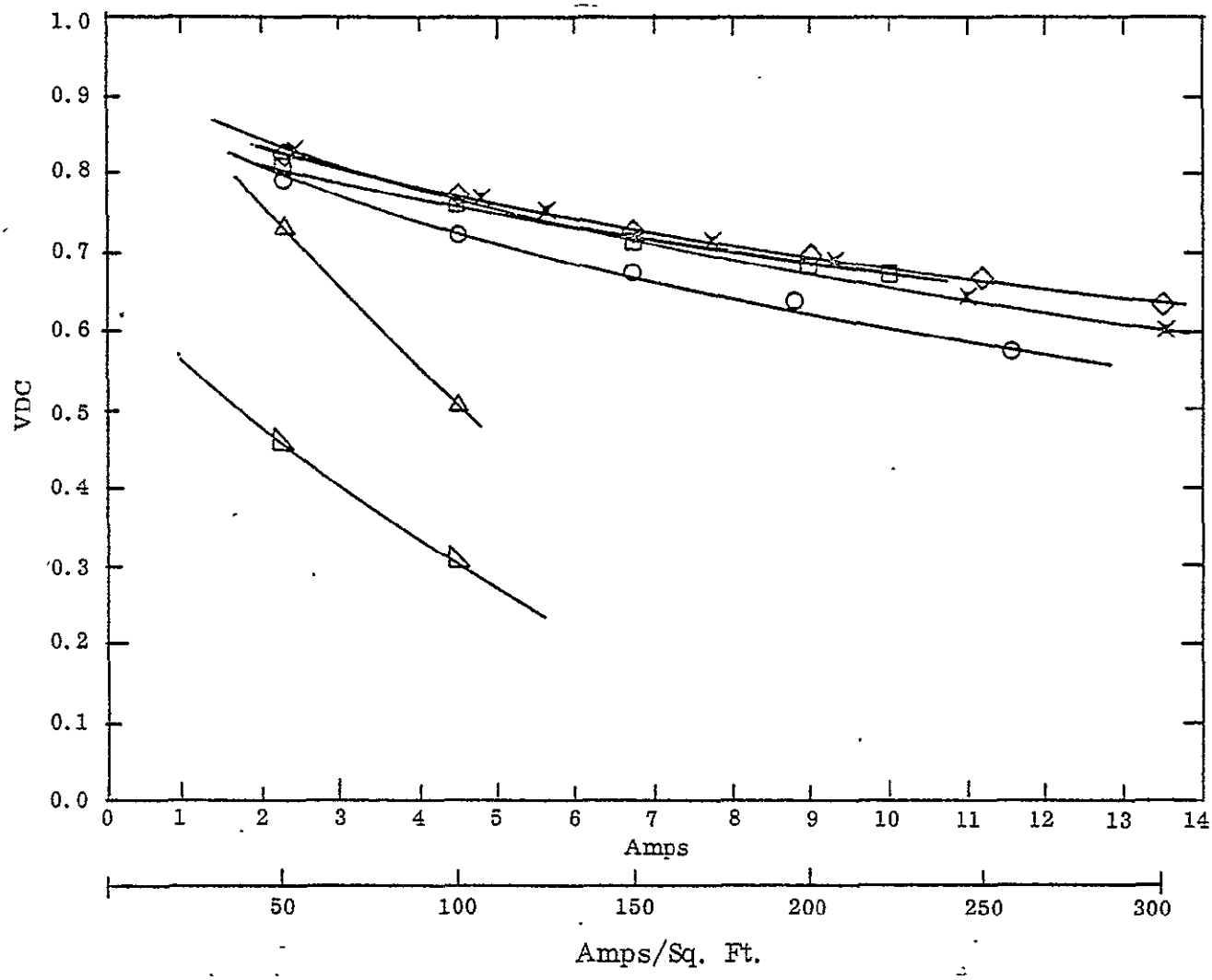
The last five cells fabricated in this subtask all contained a small amount of tungsten oxide in the anode. The best performer of these cells was NT-1-9 which contained 15% WO_2 and 21% Ru alloyed with the anode platinum. The performance of NT-1-9 on O_2/H_2 and air/H_2 reactants is shown on Figure 11. This figure shows performance slightly above baseline with these reactants. When operated on contaminated hydrogen performance was considerably improved over the baseline as displayed on Figure 12. This figure shows a high level of performance utilizing a fuel containing 10 PPM CO. Stability under these conditions was demonstrated by the five days of invariant performance. The increased amount of CO to the 0.3% level resulted in a small shift downward in performance but still much improved over baseline performance. A slow degradation of performance (i.e., 0.00035 V/hour @ 165°F and 100 ASF) was noted with continued operation on the 0.3% CO contamination in the fuel. Complete recovery to initial performance was noted, however, when a change over to pure hydrogen was completed.

Cell NT-1-9 was also operated on a very dilute fuel (i.e., 33% H_2 - 25% CO_2 - 42% N_2) with resultant performance shown on Figure 13. The excellent performance demonstrated at the 1.75 times stoichiometric flow indicated the inherent capability of the cell to operate on very low partial pressures of hydrogen.

TABLE II

Cell Configurations and Performance Comparison

Fuel Cell Number NASA Technology -Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-1-1	Anode catalyst 50% Pt-50% Ru mixed with 15% T-42	-0.143	-		
NT-1-1-A	Same as above except with Vexar compression screens in cathode gap	-0.130	-0.210		
NT-1-2	Anode catalyst 50% Pt-50% Rh mixed with 15% T-42	0.000	+0.005		
NT-1-3	Anode catalyst 50% Pt-50% Ir mixed with 15% T-42	-	-		
NT-1-4	Anode catalyst 75% Pt-25% Ru mixed with 15% T-42	-0.017	+0.004		
NT-1-5	Anode catalyst 85% Pt-15% WO_2 mixed with 15% T-42	-0.025	-0.018		
NT-1-6	Anode catalyst 85% Pt-15% $WO_{2.5}$ mixed with 15% T-42	-0.040	-0.038		
NT-1-7	Anode catalyst 64% Pt-21% Ru-15% WO_2 mixed with 15% T-42	-0.023	-0.027		
NT-1-8	Anode catalyst 64% Pt-21% Ru-15% $WO_{2.5}$ mixed with 15% T-42	-0.055	-0.075		
NT-1-9	Anode catalyst 64% Pt-21% Ru-15% WO_2 mixed with 15% T-42	+0.023	+0.035	+0.012	+0.021



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

X - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow
R = 0.0126 ohm

△ - O_2/H_2 (25% CO_2 - 0.3% CO - 0.1% CH_4)
@ 1.25 stoich (165°F) R = 0.016 ohm

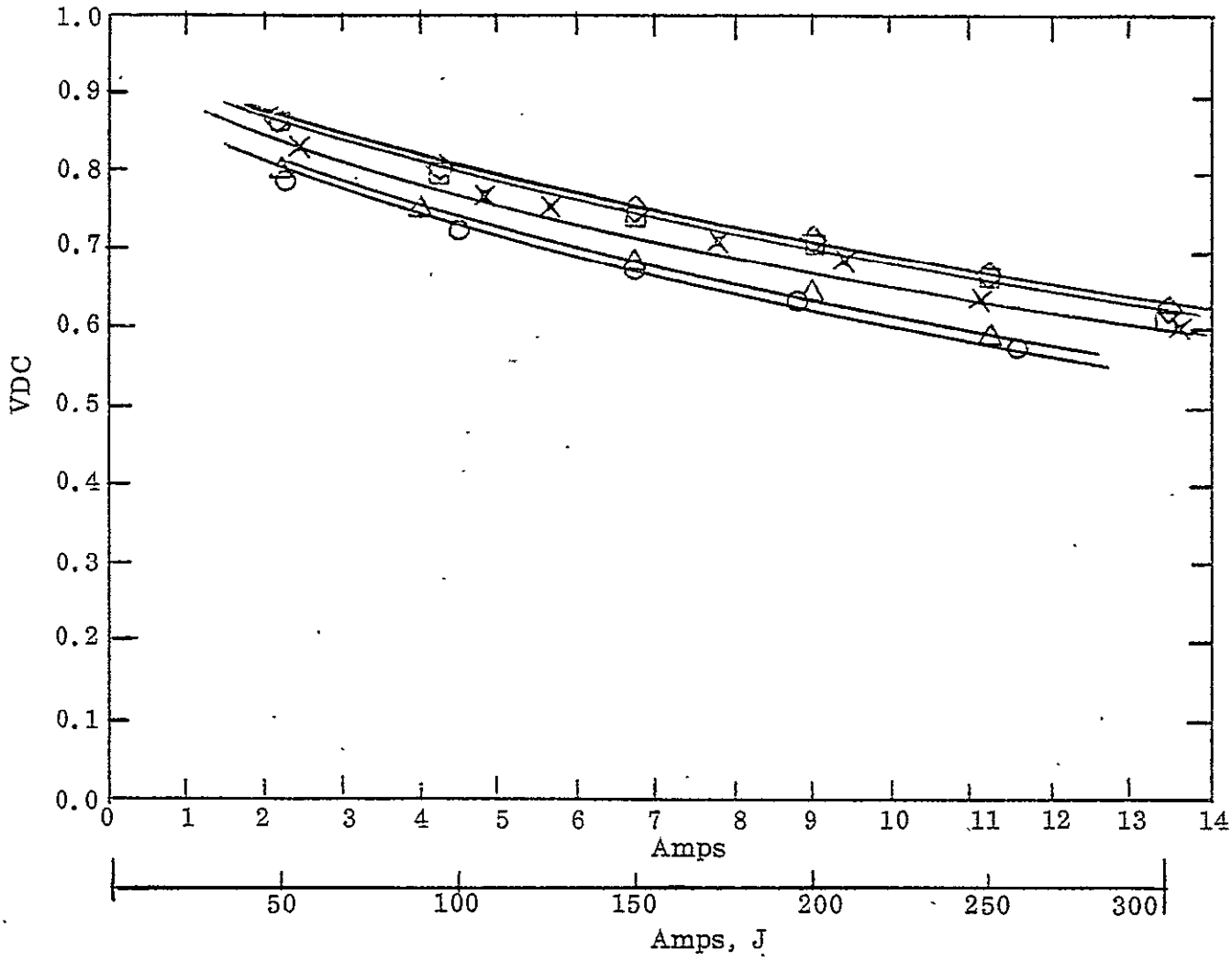
Fuel Cell NT-1-4 (25% Ru Anode)

□ - O_2/H_2 (120°F) R = 0.0105 ohm

◇ - O_2/H_2 (165°F) R = 0.0095 ohm

△ - O_2/H_2 (25% CO_2 - 0.3% CO - 0.1% CH
@ 1.25 stoich (165°F)
R = 0.0095 ohm

Figure 10.



Baseline Cell (1974)

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

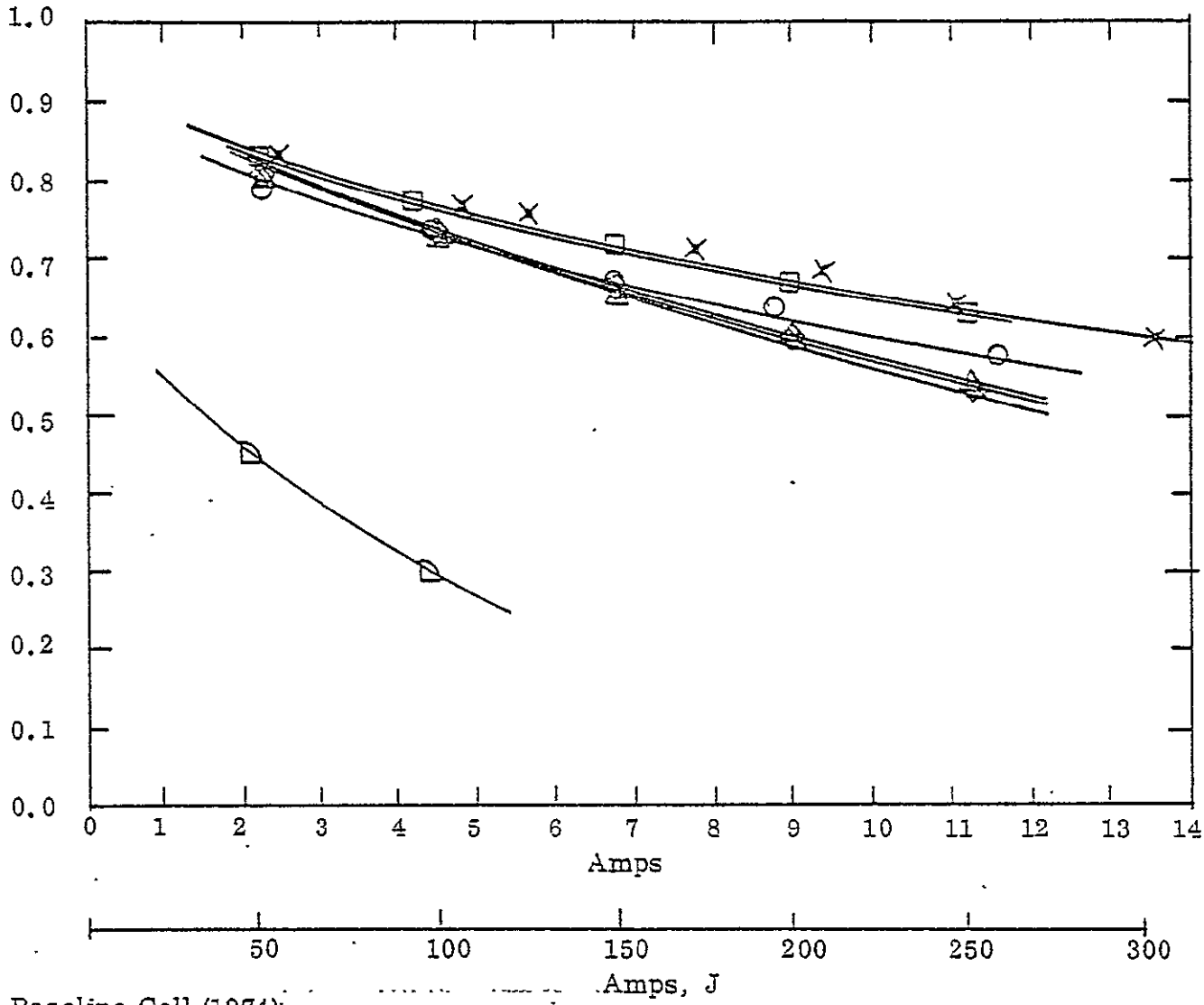
Fuel Cell NT-1-9 (15% WO_2 - 21% RU Anode)

□ - O_2/H_2 (120°F) R = 0.010 Ohm

◇ - O_2/H_2 (165°F) R = 0.009 Ohm

△ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.009 Ohm

Figure 11.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

X - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

□ - O_2/H_2 (25% CO_2-0.3% 1.25 stoich (165°F) R = 0.016 ohm

Fuel Cell NT-1-9 (15% WO_2 - 21% Ru Anode)

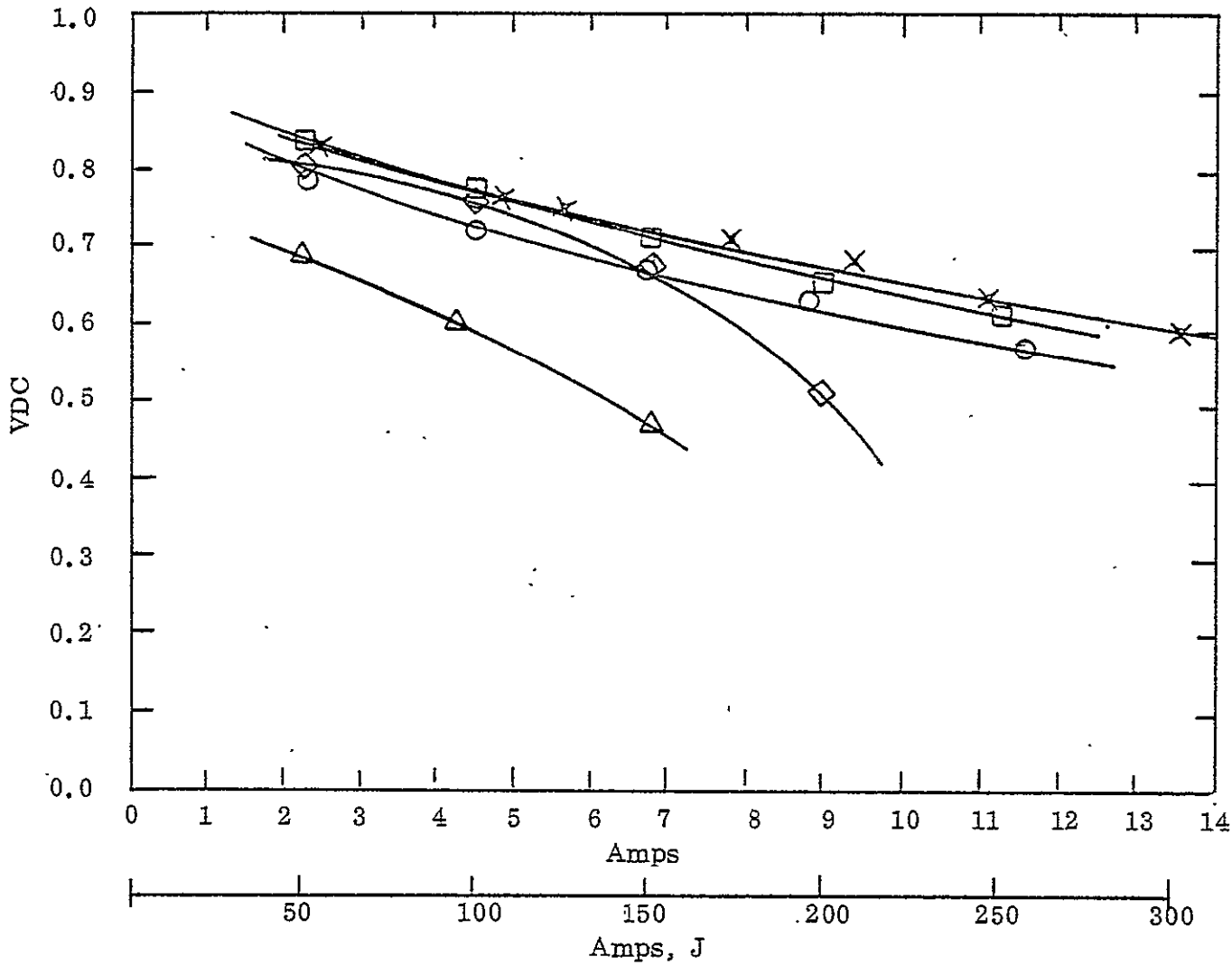
⊡ - O_2/H_2 (25% CO_2-10 PPM CO-0.3% CH_4)@1.25 st (165°F) R = 0.00825 Ohm initial and 5 days after changeover

◇ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4 @ 1.25 stoicl (165°F)R = 0.008 Ohm 6 hours after gas changeover

△ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4)@1.5 stoich R = 0.008 Ohm 6 hours after gas changeover

◺ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4)@ 1.25 sto (165°F) R = 0.008 Ohm 24 hours after crossov

Figure 12.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-1-9 (15% WO_2 - 21% RU Anode)

□ - O_2/33% H_2 - 25% CO_2 - 42% N_2 (165°F)
1.75 x fuel stoich flow
R = 0.009 ohm

◇ - O_2/33% H_2 - 25% CO_2 - 42% N_2 (165°F)
1.5 x fuel stoich flow
R = 0.009 ohm

△ - O_2/33% H_2 - 25% CO_2 - 42% N_2 (165°F)
1.25 x fuel stoich flow
R = 0.009 ohm

Figure 13.

3.1.2 SPE Membrane Performance

The purpose of this subtask was to demonstrate lower cost and/or higher fuel cell performance through the use of alternate membrane electrolytes.

The approaches taken in this subtask were threefold. First, a membrane having all the physical and chemical characteristics of the baseline electrolyte, except it had only one-half the thickness (5 mils) (.1270 mm), was selected for investigation. The thicker 10 mil (.2540 mm) material was selected for use many years ago when basic polymer imperfections could have lead to failure. With today's high quality materials, this extra thickness is not required. The advantage of the 5 mil material is its higher potential performance by means of its lower internal impedance. The thinner material also offers some cost advantages.

The second approach taken in this subtask was to utilize a chemistry variation of the duPont Nafion (R) polymer utilized in the baseline cell. This variation had a greatly increased acid content as measured by the increase of the ion exchange capacity. As is the base with all currently utilized solid polymer electrolytes utilized at DECP, this material had its acid chains chemically linked or fixed to the polymer, thus preventing dilution or loss of the electrolyte. The advantage of the higher acid content polymer is the still higher electrical performance from further reductions in internal impedance.

The third and final approach taken in this subtask was to perform initial evaluations on a new solid polymer electrolyte. This polymer is manufactured by Radiation Applications Industries Research Corporation (RAI). The fabrication is conducted by grafting $\alpha\beta\beta$ -trifluorostyrene to FEP. The advantage of this new polymer is its potential for a large reduction in raw material cost.

A total of seven cells were fabricated to the 1974 baseline configuration except for variation in the electrolyte materials. Table III displays a brief description of each cell configuration and a numerical comparison of O_2/H_2 and air/H_2 performance with the 1974 baseline.

Two cells containing the 5 mil Nafion (R) polymer with the baseline acid content were fabricated and test evaluated. Figure 14 displays the performance of cell NT-2-5 as compared to the 1974 baseline performance. Note that the abscissa scale has been changed from previous plots to display the high current density capabilities of this thinner electrolyte. Although no performance improvement was noted at lower current densities, significant higher current density performance increases were established.

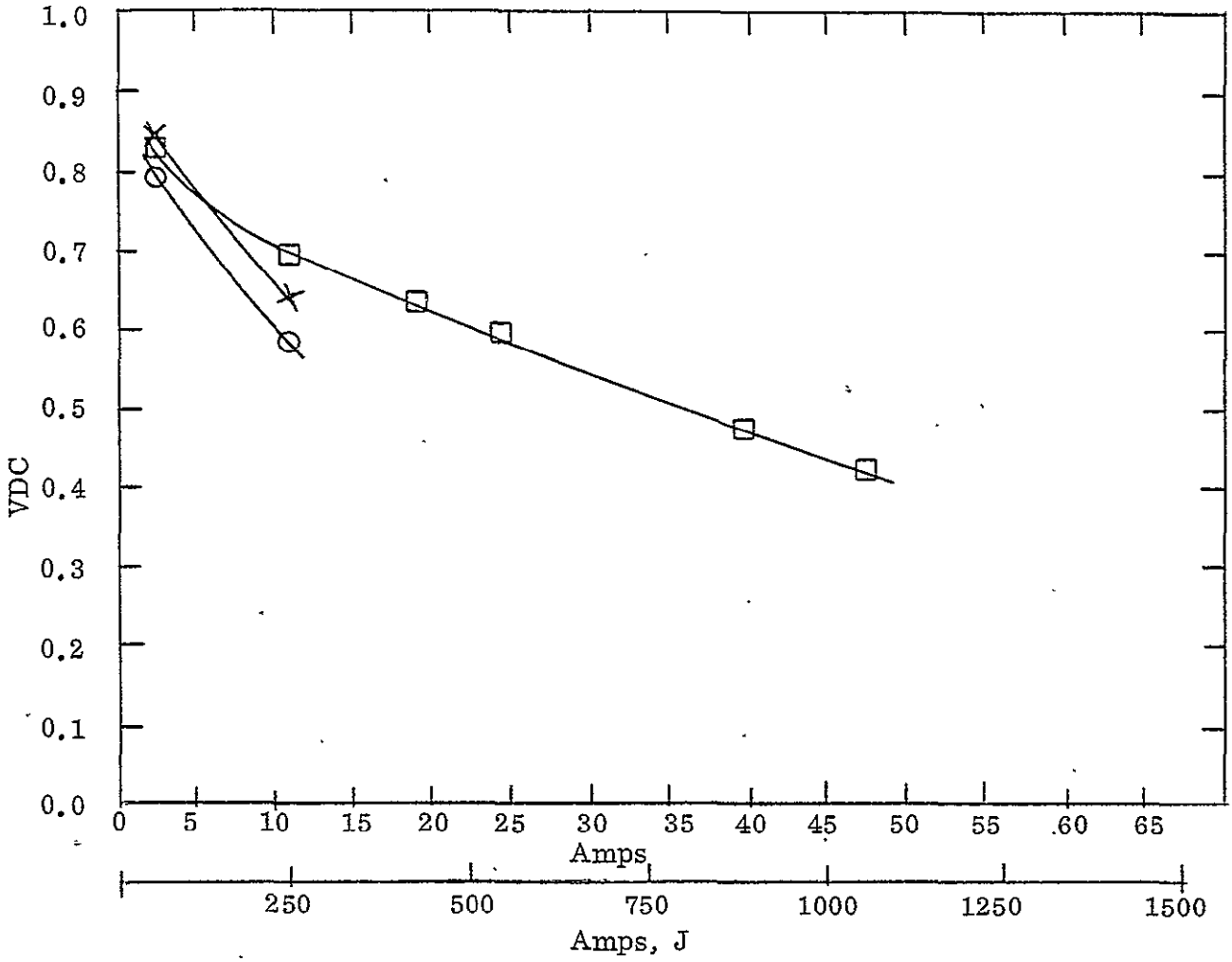
TABLE III

Cell Configurations and Performance Comparisons

Fuel Cell Number NASA Technology -Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-2-1	5 mil Nafion® with 24% H_2O	-0.005	+0.035		
NT-2-2	High IEC 4 mil Nafion® with 52% H_2O	-	-		
NT-2-3	High IEC 6 mil RAI membrane at 33% H_2O	-0.095	-0.090		
NT-2-4	High IEC 4 mil Nafion® with 30% H_2O	-	-		
NT-2-5	5 mil Nafion®	-0.035	+0.009		
NT-2-6	High IEC 6 mil RAI membrane @ 33% H_2O 350°F/750 psi cathode attachment 305°F/250 psi 2nd cathode attachment	-0.001	-0.031	-0.293	-
NT-2-7	Cell NT-2-6 with LNP replaced with Chemplast at 305°F/250 psi	-0.010	-0.029	-0.220	-

Two cells containing the high acid content - high IEC Nafion® were fabricated. Neither cell was capable of operation as cross leakage was identified before activation. One of the disadvantages of the high IEC material is its reduced physical strength. After the second attempt, it became obvious that the present DECP assembly techniques and/or design configurations were not suitable for the high IEC polymer.

The RAI polymer electrolyte was evaluated in three cell assemblies. Figure 15 displays cell NT-2-6 which was the best performer of the three. This cell showed performance equivalent to the 1974 baseline at lower current densities, but not quite as good at high current densities.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

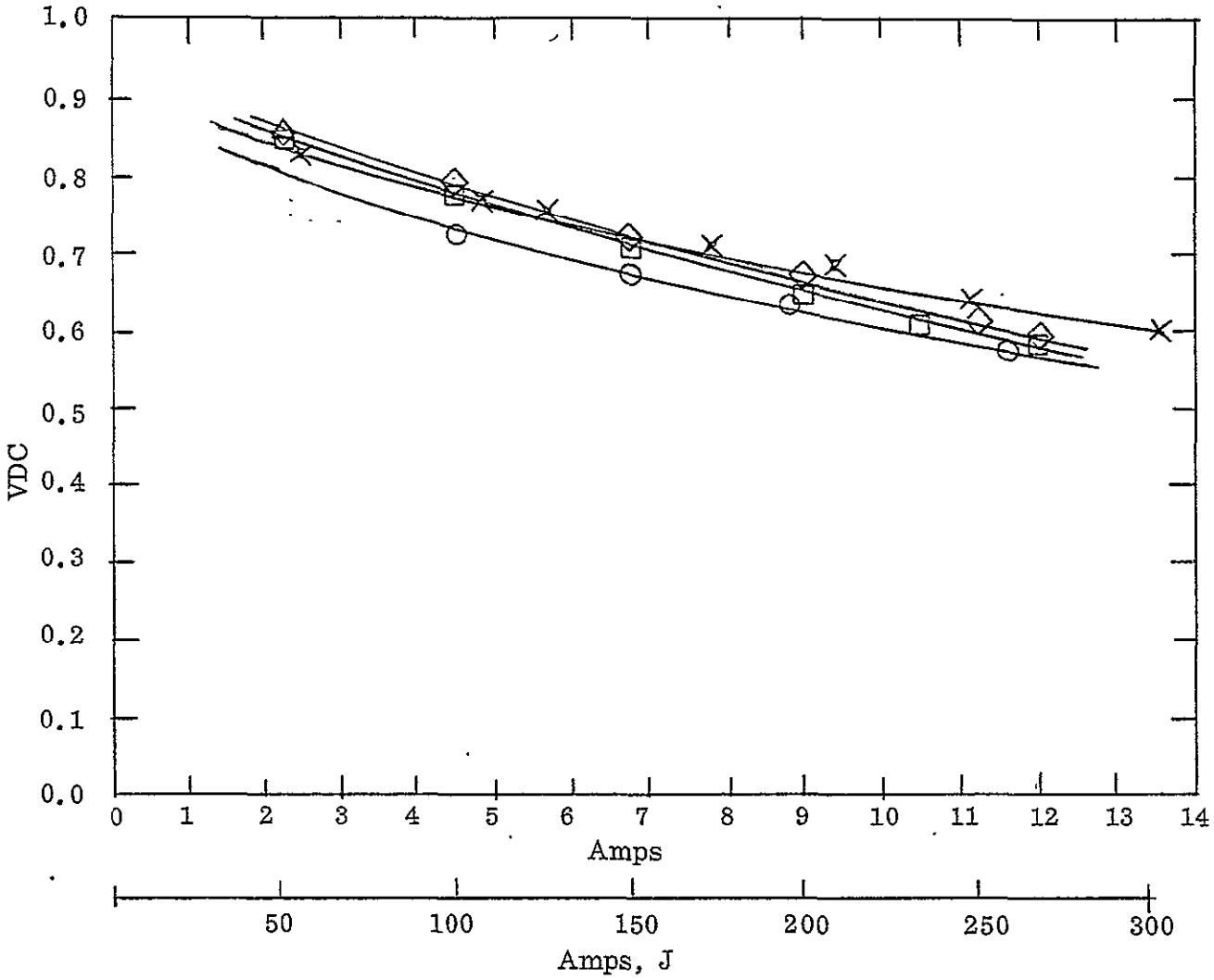
X - O_2/H_2 (120°F) R = 0.0135 Ohm

O - Air/H_2 (165°F) 2.5 x air stoich flow
R = 0.0126 ohm

Fuel Cell NT-2-5 (5 Mil Nafion®)

□ - O_2/H_2 (165°F) R = 0.005 Ohm

Figure 14.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

X - O_2/H_2 (120°F) R = 0.0135 ohm

O - Air/H_2 (165°F) 2.5 x air stoich flow
R = 0.0126 ohm

Fuel Cell NT-2-6 (6 Mil RAI)

□ - O_2/H_2 (120°F) R = 0.007 Ohm

◇ - O_2/H_2 (165°F) R = 0.0065 Ohm

Figure 15.

3.1.3 Cathode Catalyst Performance

The purpose of this subtask was to demonstrate improved cathode performance through the use of alloy catalysts.

The approach taken was to conduct a literature search and to incorporate potential candidate alloys in the laboratory 3 x 3 hardware for evaluation. One of the four cells fabricated contained a gold/platinum alloy prepared by the NASA/Lewis Research Center. This alloy was previously found to significantly improve cathode performance when utilized with an alkaline fuel cell.

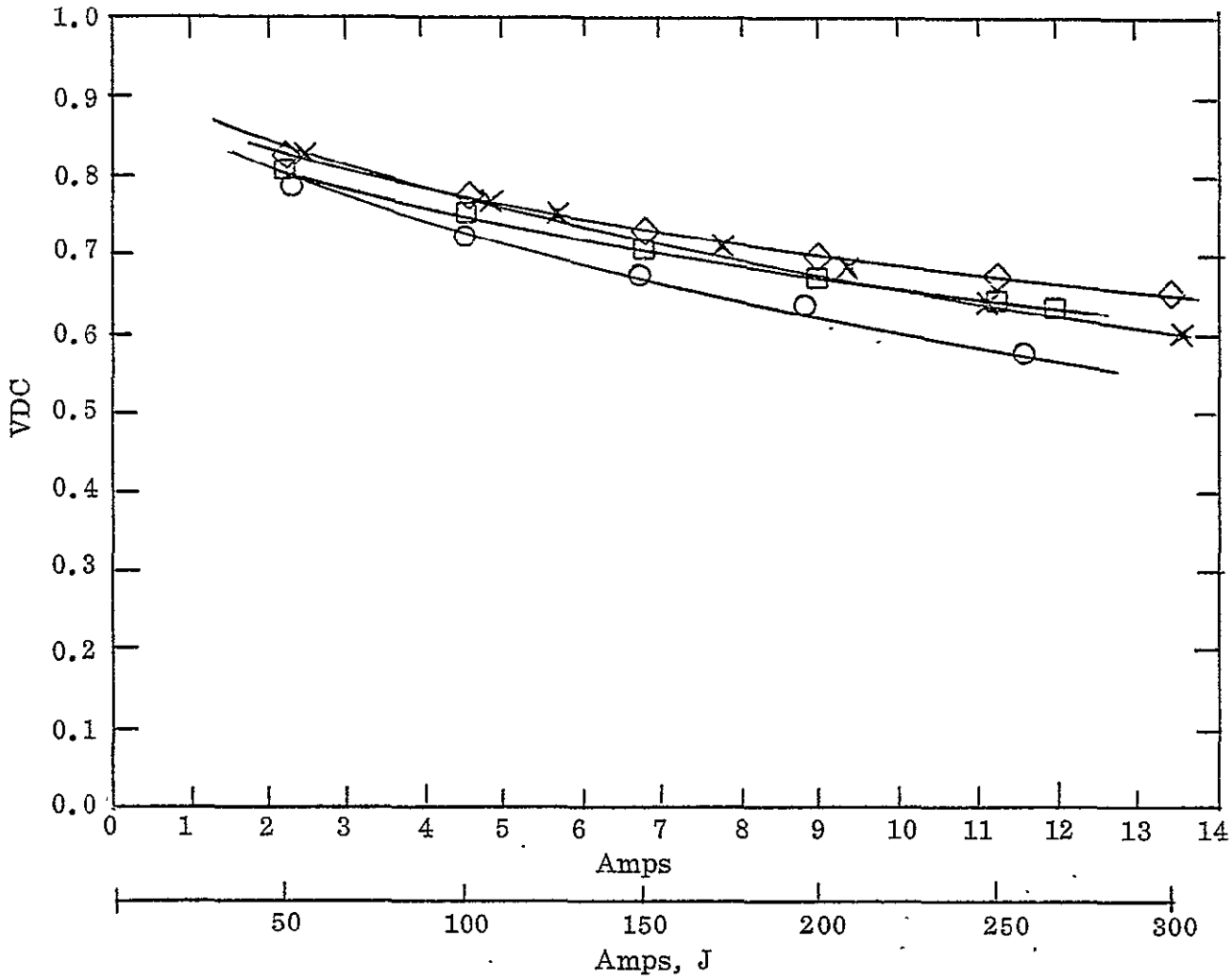
Table IV displays a brief description of the configurations of the four-cell along with a numerical comparison of O_2/H_2 and air/H_2 performance with the 1974 baseline cell.

TABLE IV

Cell Configurations and Performance Comparisons

Fuel Cell Number NASA Technology -Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-3-1	5% Ir in cathode catalyst with 12.5% T-42	-0.026	-0.005	-0.135	-
NT-3-2	5% Ru in cathode catalyst with 12.5% T-42	-0.020	-0.004	-0.115	-0.152
NT-3-3	90% Au in cathode catalyst with 12.5% T-42	-0.302	-	-	-
NT-3-4	NASA Lewis preparation 90% Au in cathode catalyst with 12.5% T-42	-0.400	-	-	-

The best performer of the four cells was NT-3-2 which contained 5% Ru in the cathode catalyst. Figure 16 displays this performance. This performance was found to be slightly below the 1974 baseline configuration. The two cells fabricated with the gold/platinum alloy cathode catalyst were found to perform well below the baseline performance. Figure 17 shows the performance of cell NT-3-3 which contained a GE/DECP prepared gold/platinum alloy and Figure 18 exhibits the performance of cell NT-3-4 containing the NASA-Lewis prepared gold/platinum alloy.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

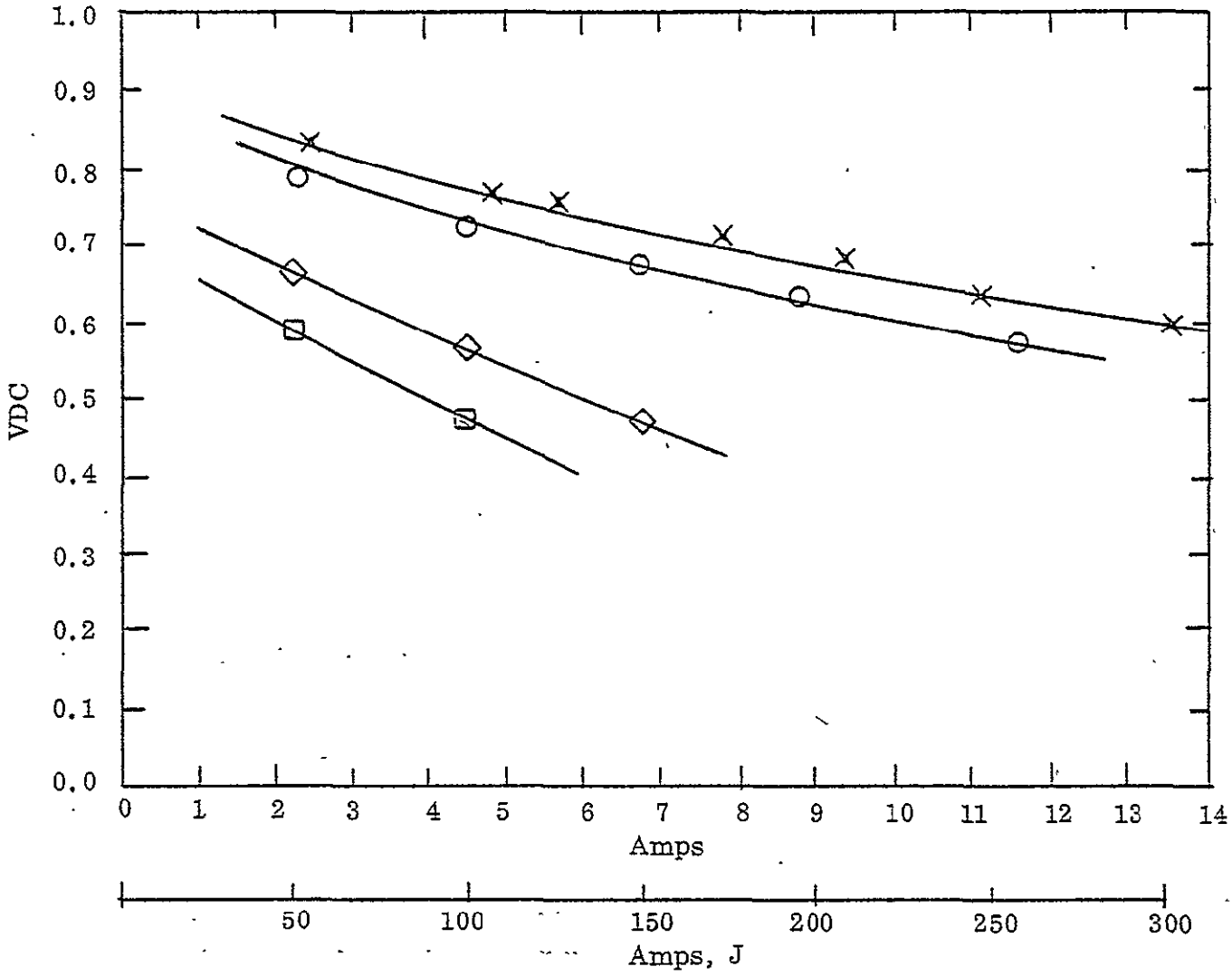
○ - Air/H_2 (165°F) 2.5 x air stoich flow
R = 0.0126 ohm

Fuel Cell NT-3-2 (5% Ru Cathode)

□ - O_2/H_2 (120°F) R = 0.0065 Ohm

◇ - O_2/H_2 (165°F) R = 0.0060 Ohm

Figure 16.



Baseline Cell (1974)

× - O_2/H_2 (120°F) R = 0.0135 ohm

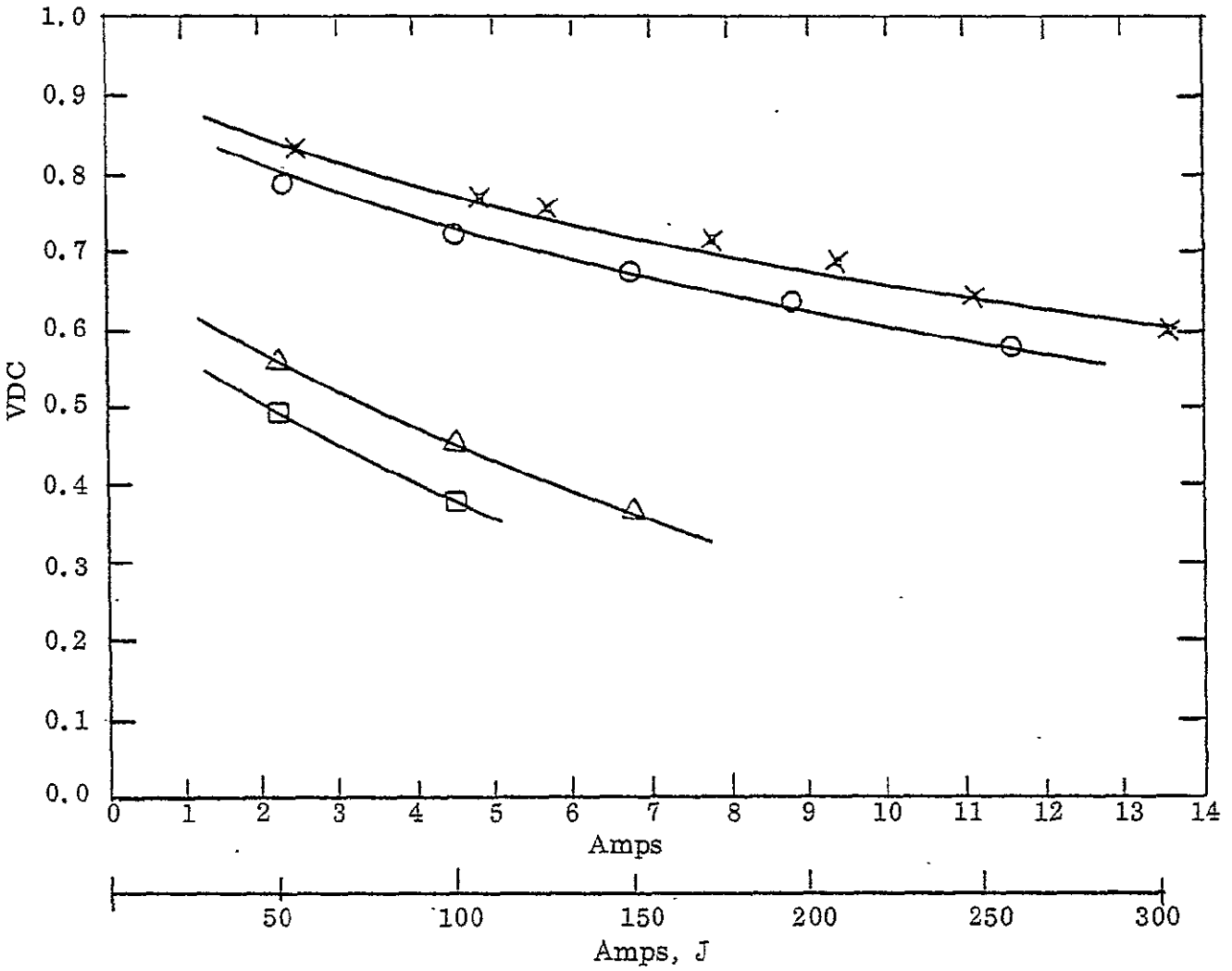
○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 Ohm

Fuel Cell NT-3-3 (90% AU Cathode)

□ - O_2/H_2 (120°F) R = 0.023 Ohm

◇ - O_2/H_2 (165°F) R = 0.0215 Ohm

Figure 17.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich
R = 0.0126 ohm

Fuel Cell NT-3-4 (NASA Lewis Catalyst in Cathode

□ - O_2/H_2 (120°F) R = 0.011 ohm

△ - O_2/H_2 (165°F) R = 0.0105 ohm

Figure 18.

3.1.4 Wetproofing Performance

The original purpose of this subtask was to investigate conductive wetproofing to reduce the IR loss in the cathode electrode. The purpose was expanded as the program continued to include the investigation of alternate wetproofing films and alternate assembly techniques.

A total of eight cells were fabricated and evaluated as part of this subtask. Table V gives a brief configuration description of each of these cells along with the numerical comparison of O_2/H_2 and air/H_2 performance with the 1974 baseline cell.

The first attempt to reduce the cathode IR loss was to eliminate the wetproofing film altogether such that current pickup from the cathode could be accomplished at any point on the electrode. To compensate for the removed wetproofing film, the teflon content within the catalyst was increased from 12.5% to 20%. Operation of this cell NT-4-1 was found to be unstable.

Cell NT-4-3 utilized a gold impregnated wetproofing such that it became highly conductive. Unfortunately, overall cell performance reduced in this configuration as can be seen on Figure 19.

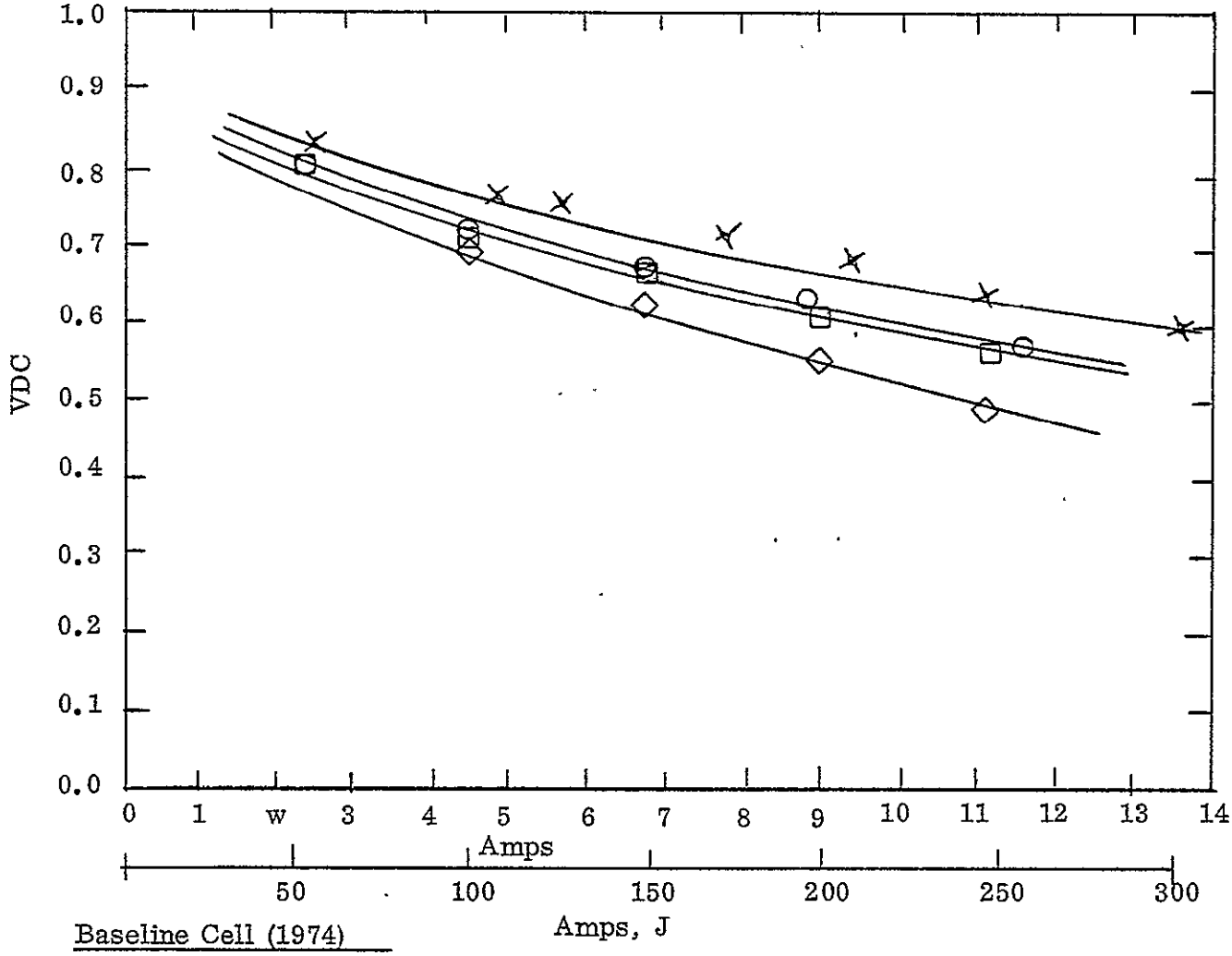
The repeatability of cell performance from cell to cell while operating on air as the source of oxidant became of some concern as the program continued. This concern included an observed variability in the porosity of the GE/DECP prepared wetproofing film. Cells NT-4-4 thru NT-4-7 were fabricated and test evaluated to improve this observed variability. These configurations included the use of a highly uniform commercial substitute for the DECP prepared wetproofing and they also contained variations in the cell assembly techniques. Fuel cell NT-4-8 was fabricated utilizing what was considered to be the best combination of characteristics from the evaluation of NT-4-4 thru NT-4-7.

Figure 20 displays the performance of cell NT-4-8 with its significantly improved performance over the baseline hardware. In order to determine the stability of this configuration with operating time an endurance test was performed. Figure 21 shows that in actuality performance tended to increase for the first 800 hours and then became quite stable.

TABLE V

Cell Configurations and Performance Comparison

Fuel Cell Number NASA Technology -Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-4-1	20% T-30 mixed into cathode catalyst no wetproofing	-	-	-	-
NT-4-2	Chemplast wetproofing cathode assembled at 500 psi	-0.054	-0.034	-0.370	-
NT-4-3	Gold plating in LNP	-0.063	-0.070	-0.035	-0.060
NT-4-4	Chemplast wetproofing single cathode @ 305°F/250 psi	-0.042	-0.030	-0.095	-
NT-4-5	Cell NT-4-2 Chemplast replaced with 300 psi Chemplast cathode	-0.037	-0.025	-0.115	-
NT-4-6	Baseline with wetproofing refinements	-0.015	-0.005	+0.010	+0.030
NT-4-7	Baseline with wetproofing refinements using double press single cathode	-0.088	-0.148	-0.169	-
NT-4-8	Baseline with wetproofing refinements using Chemplast wetproofing film	+0.035	+0.050	+0.020	+0.015



Baseline Cell (1974)

Cathode Pressure - 35" H_2O

Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

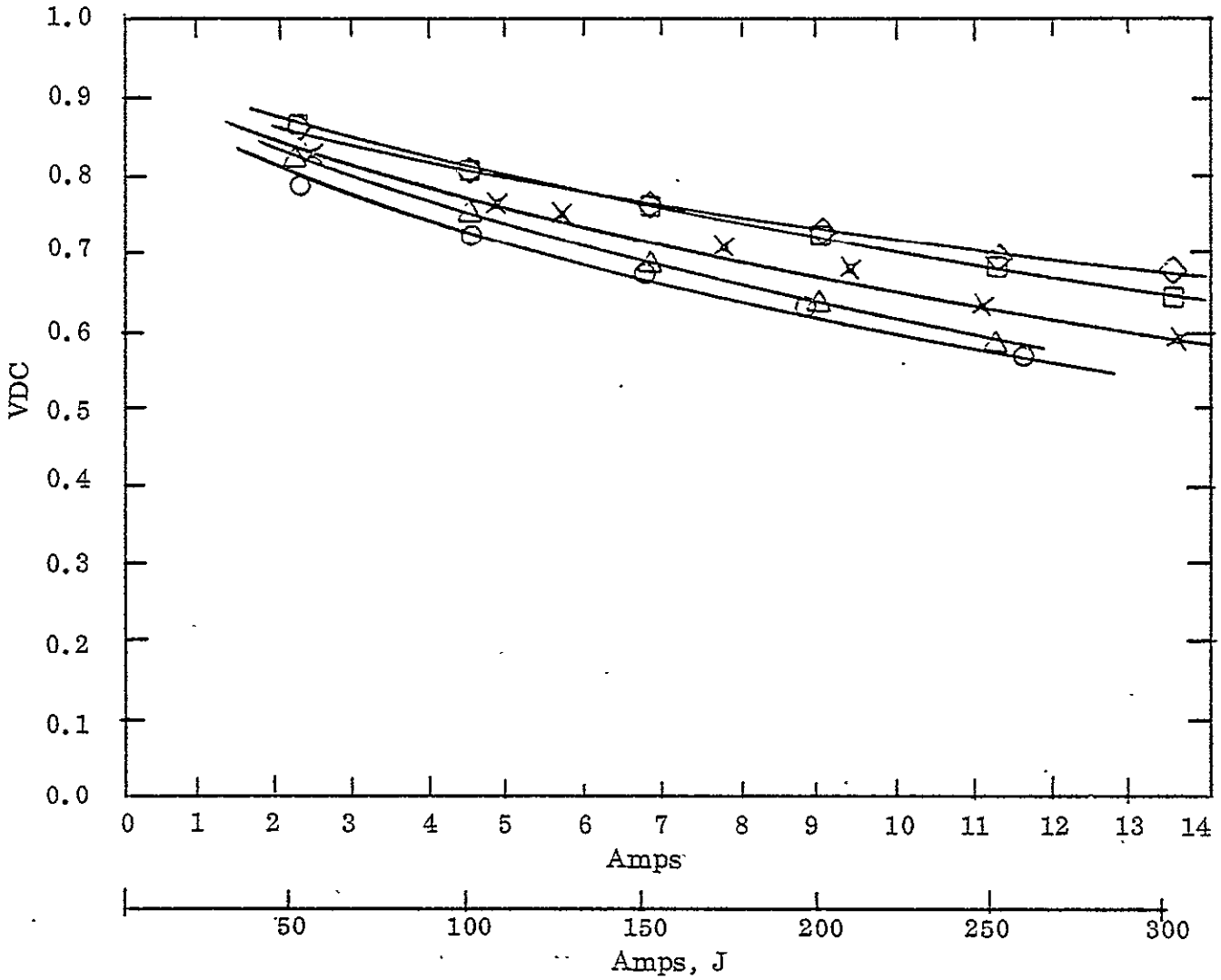
○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-4-3 (Gold Plated Wetproofing)

□ O_2/H_2 (120°F) R = 0.009 Ohm

◇ Air/H_2 (165°F) R = 0.0085 Ohm

Figure 19.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-4-8 (Refinements and Chemplast)

□ - O_2/H_2 (120°F) R = 0.007 ohm

◇ - O_2/H_2 (165°F) R = 0.006 ohm

△ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.006 Ohm

Figure 20.

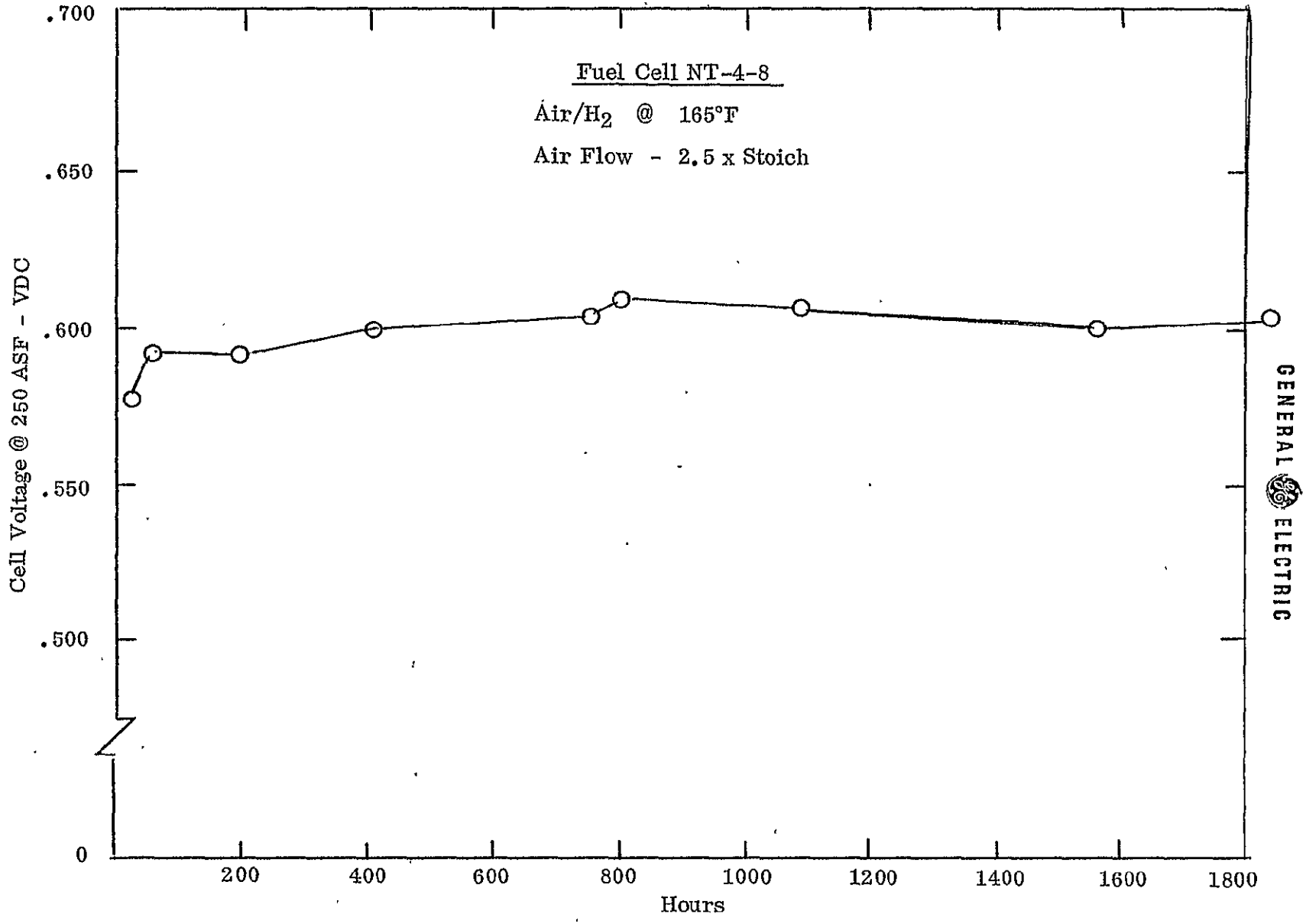


Figure 21. Cell Voltage vs. Time

3.1.5 Catalyst Loading

The purpose of this subtask was to demonstrate reductions in the amount of noble metal required in the catalyst systems.

The approaches taken were threefold. The first approach was to simply apply less catalyst to the solid polymer electrolyte utilizing the standard electrode manufacturing techniques. The second approach was to apply less catalyst per the first approach and then to add a second layer of low cost conductive material onto the platinum. The third approach was to utilize a low cost extender material with the reduced amount of platinum distributed throughout the blend.

A total of eight cells were fabricated and test evaluated as part of this subtask. Table VI displays the brief configuration description of each of the cells along with the numerical comparison of performance with the 1974 baseline.

Performance plots of each cell except NT-5-3 are displayed on Figures 22 thru 28. Cell NT-5-3 was not evaluated as cathode detachment occurred with normal handling. Apparently the reduced amount of catalyst material prohibited proper cathode attachment. As can be detected by examination of Figures 22 thru 28, none of the catalyst loading reduction attempts were effective as performance of each cell was significantly below the baseline cell.

3.1.6 Baseline Performance (1975) Characteristics

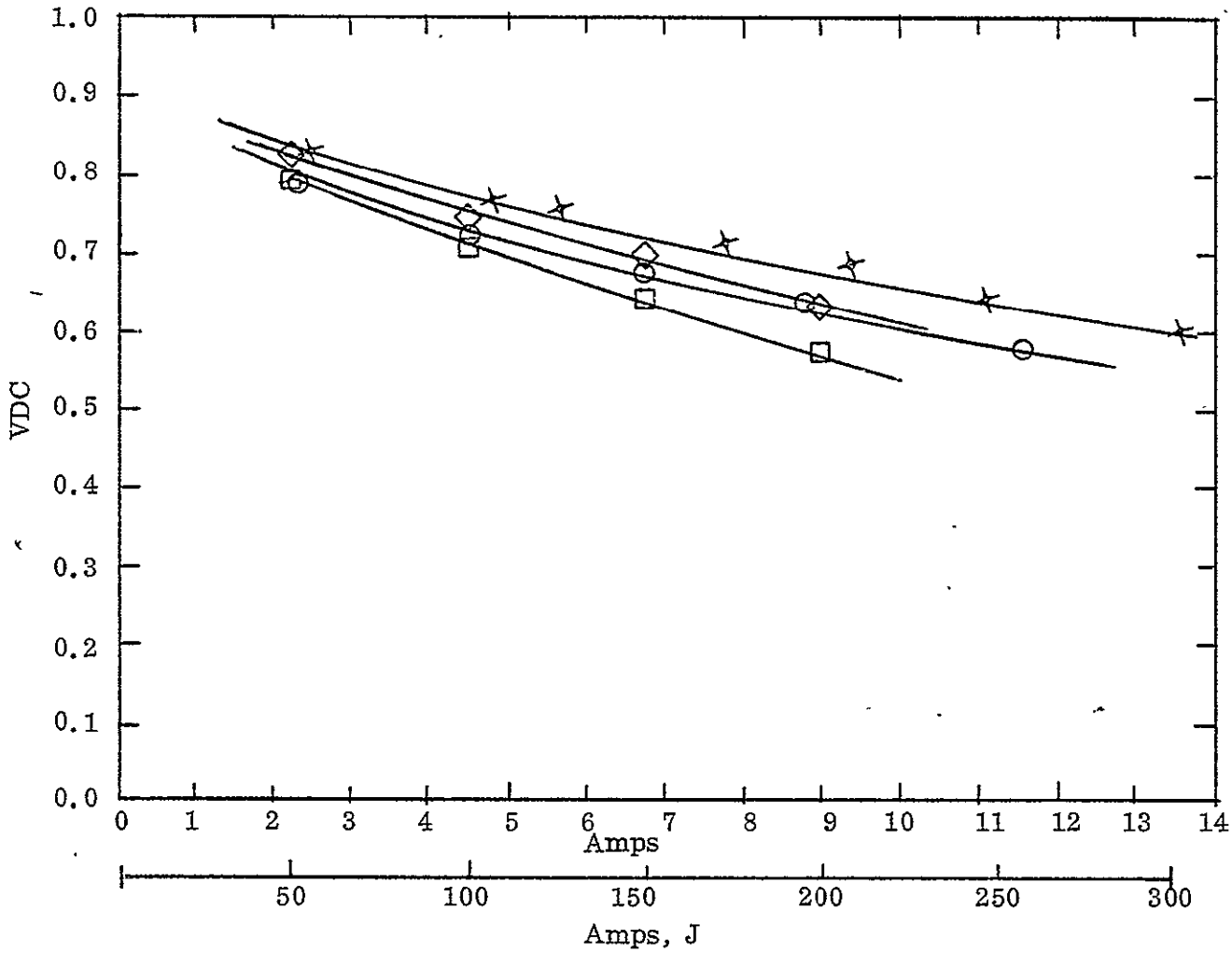
The purpose of this subtask was to incorporate several of the demonstrated advances into a single cell and establish a new baseline performance against which future modifications could be compared. These advances included:

- The SPE membrane thickness was reduced from 10 mils to 5 mils (.2540 to .1270 mm).
- The Chemplast wetproofing at a normal 7 mil (.1778 mm) thickness was utilized instead of the 7 mil LNP.
- The cathode current collection screen material was changed from 3 mil (.0762 mm) gold to 3 mil niobium.
- The anode catalyst consisted of 64% Pt - 21% Ru 15% WO_2 mixed with 15% T-42. As opposed to the pure platinum-teflon mix.

TABLE VI

Cell Configurations and Performance Comparisons

Fuel Cell Number NASA Technology-Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-5-1	1 mg/cm^2 anode catalyst loading	-0.063	-0.105	-	-
NT-5-2	1 mg/cm^2 anode catalyst loading with 3 mg/cm^2 graphite	-0.070	-0.095	-	-
NT-5-3	1 mg/cm^2 cathode catalyst loading	-	-	-	-
NT-5-4	1 mg/cm^2 cathode catalyst loading with 3 mg/cm^2 graphite	-0.160	-	-	-
NT-5-5	8 mg/cm^2 total anode metal loading. 0.43 mg/cm platinum and remainder $WO_{2.5}$	-0.220	-0.420	-	-
NT-5-6	4 mg/cm^2 total anode metal loading. 0.2 mg/cm platinum and remainder boron carbide	-0.775	-	-	-
NT-5-7	16 mg/cm^2 total anode metal loading. 0.8 mg/cm platinum and remainder WO_2	-0.104	-0.175	-	-
NT-5-8	Same as NT-5-7 except T-7 utilized in anode	-0.100	-0.170	-	-



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

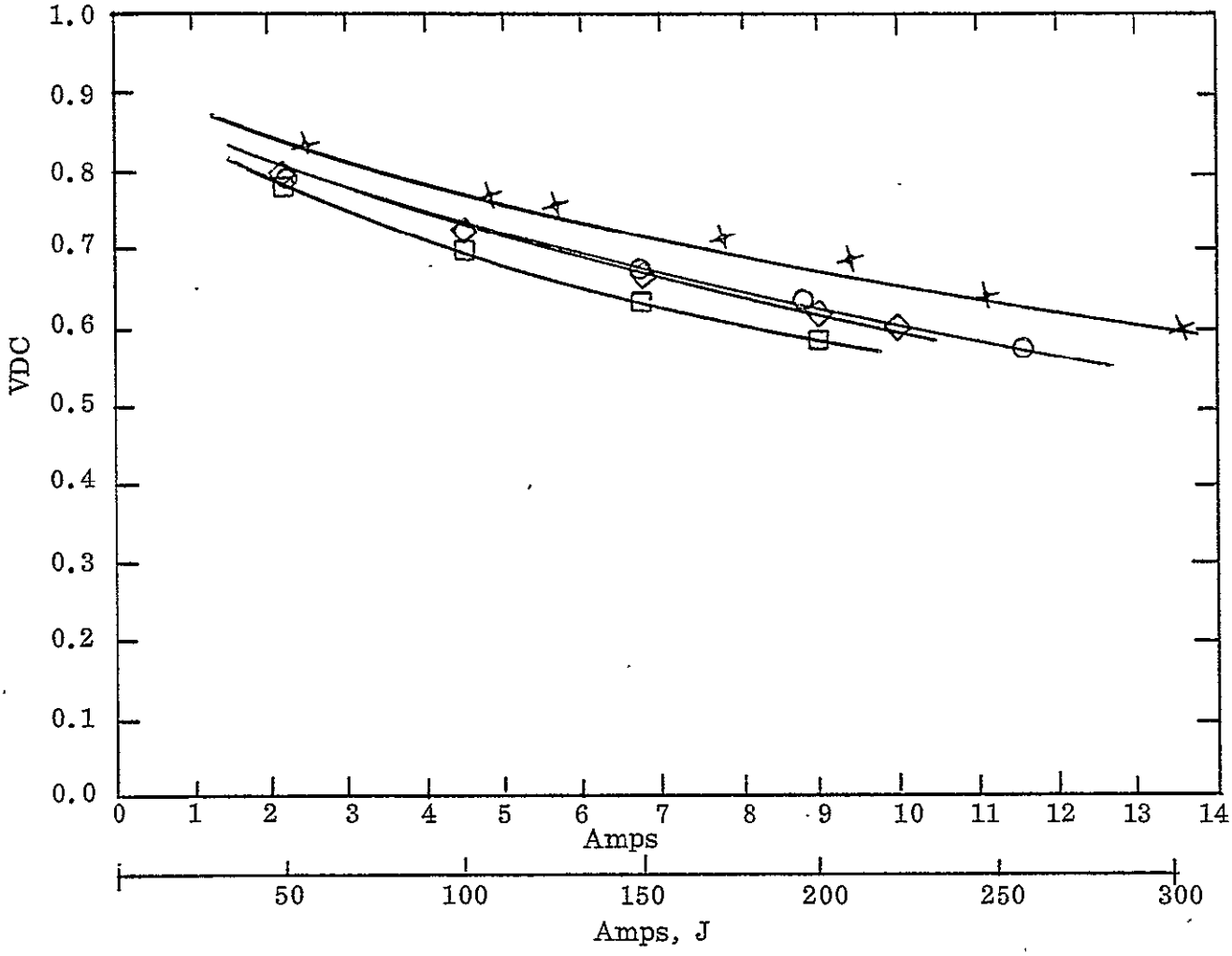
○ - Air/H_2 (165°F) 2.5 x air stoich flow
R = 0.0126 ohm

Fuel Cell NT-5-1 (1 mg/cm^2 Anode)

□ - O_2/H_2 (120°F) R = 0.0115 Ohm

◇ - O_2/H_2 (165°F) R = 0.010 Ohm

Figure 22.



Fuel Cell NT-5-2 (1 mg/cm^2 catalyst - 3 mg/cm^2 Graphite Anode

Baseline Cell (1974)

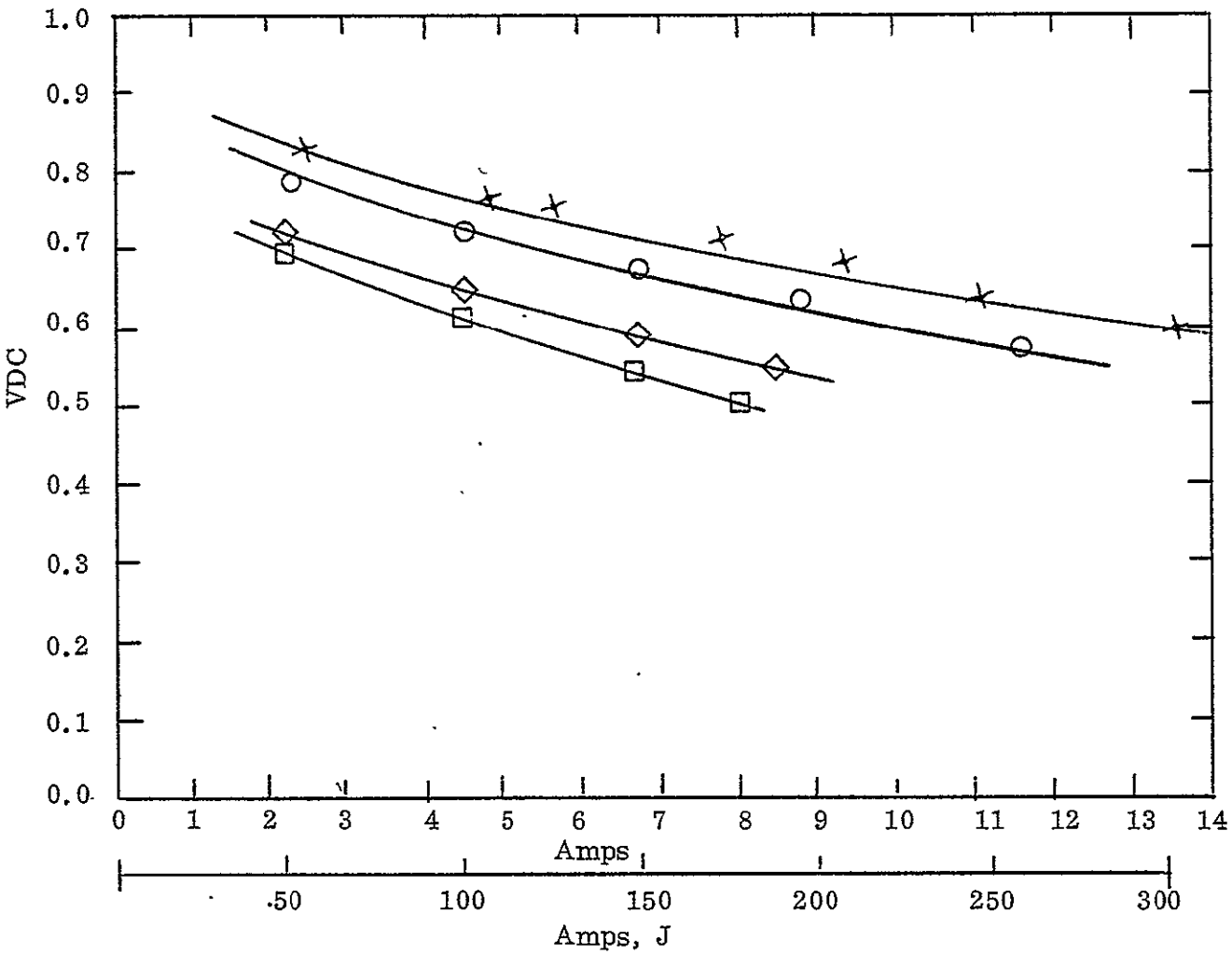
× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow
R = 0.0126 ohm

□ - O_2/H_2 (120°F) R = 0.0125 ohm

◇ - O_2/H_2 (165°F) R = 0.011 ohm

Figure 23.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

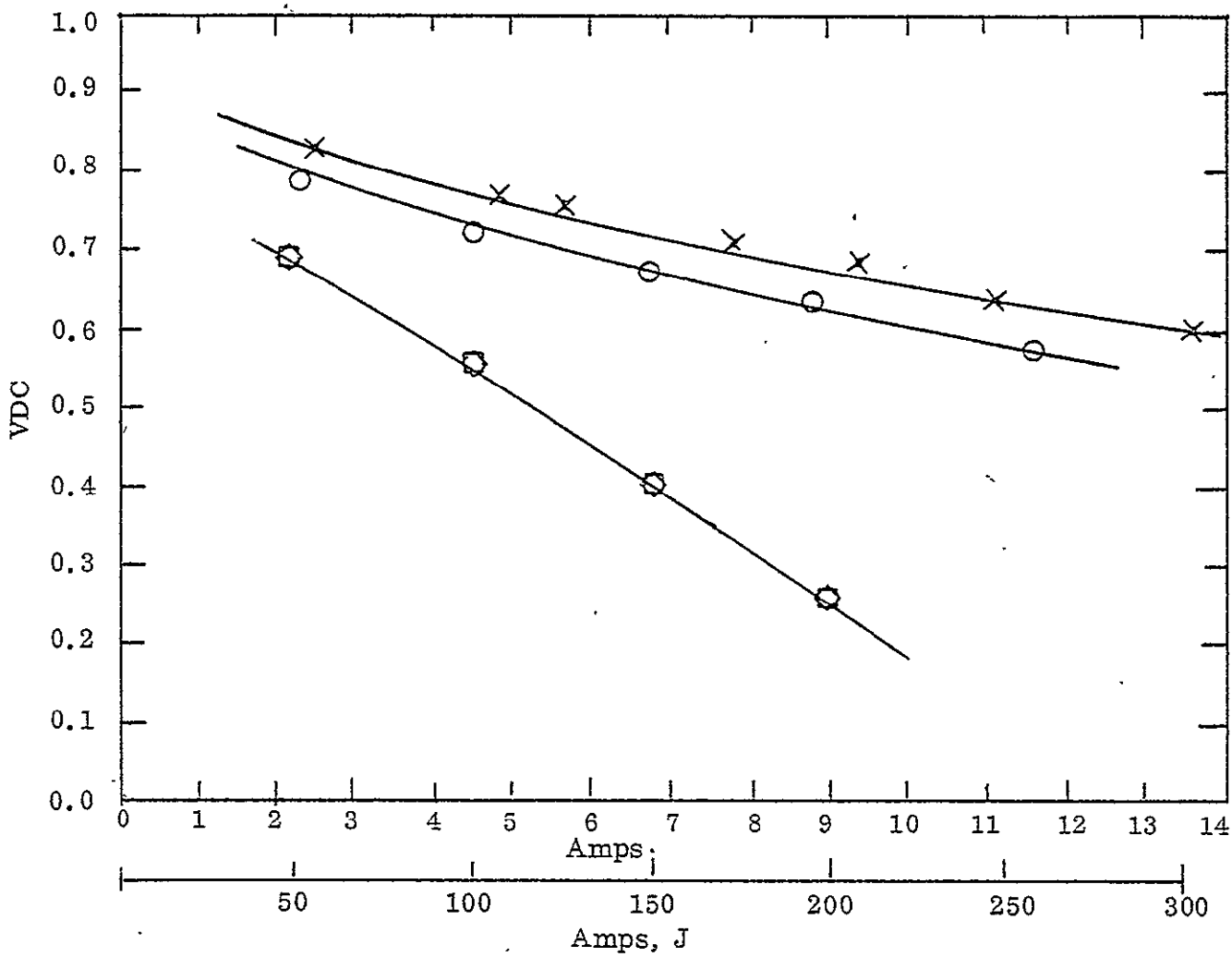
○ - Air/H_2 (165°F) 2.5 x air stoich flow
R = 0.0126 ohm

Fuel Cell NT-5-4 (1 mg/cm^2 catalyst - 3 mg/cm^2 Graphite Cathode

□ - O_2/H_2 (120°F) R = 0.013 ohm

◇ - O_2/H_2 (165°F) R = 0.012 ohm

Figure 24.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

- O_2/H_2 (120°F) R = 0.0135 ohm

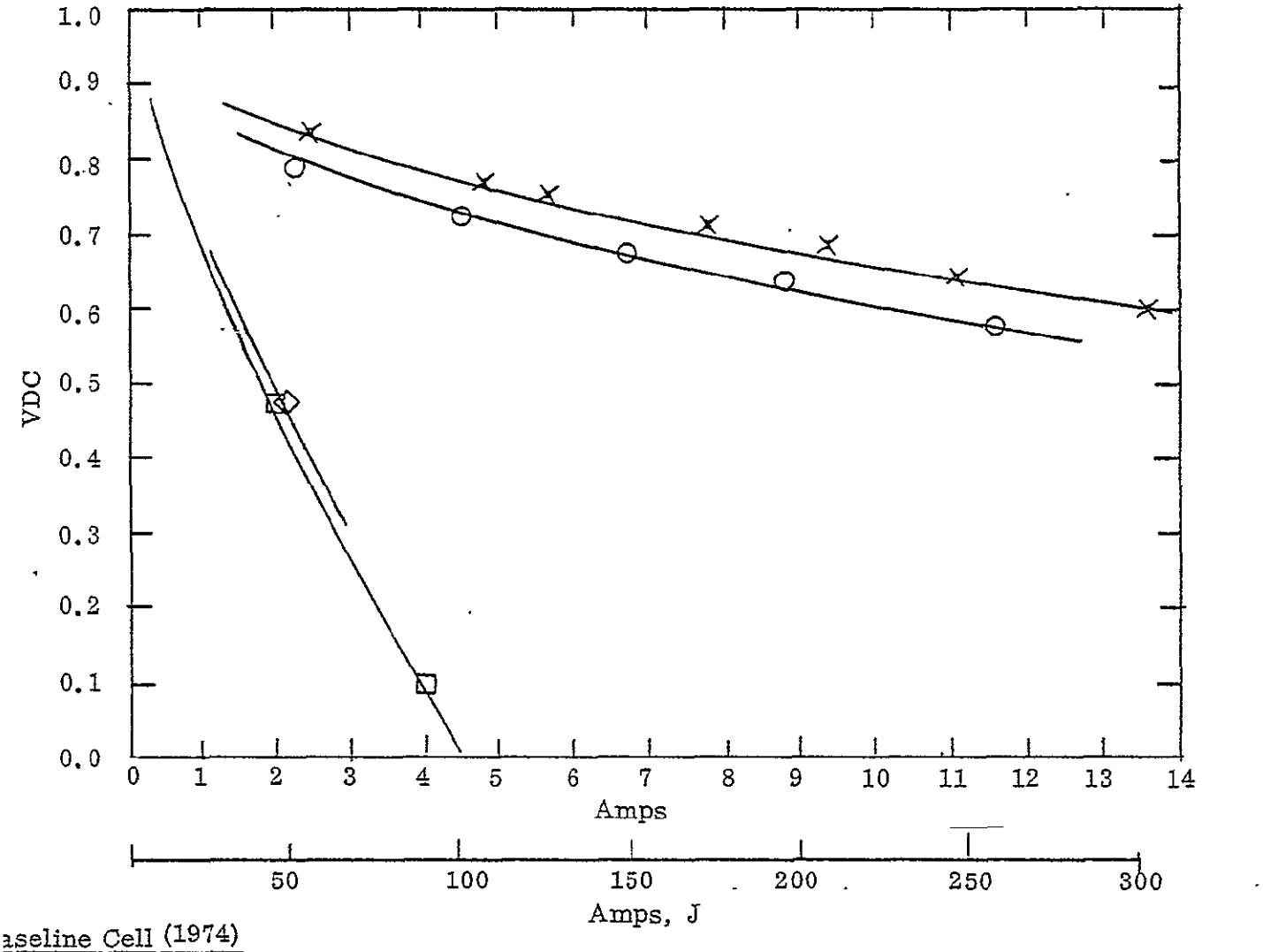
- Air/H_2 (165°F) 2.5 x air stoich flow
  R = 0.0126 ohm

Fuel Cell NT-5-5 ($WO_{2.5}$ Anode Catalyst Extender)

□ - O_2/H_2 (120°F) R = 0.044 ohm

◇ - O_2/H_2 (165°F) R = 0.040 ohm

Figure 25.



aseline Cell (1974)

athode Pressure - 35" H_2O
iode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

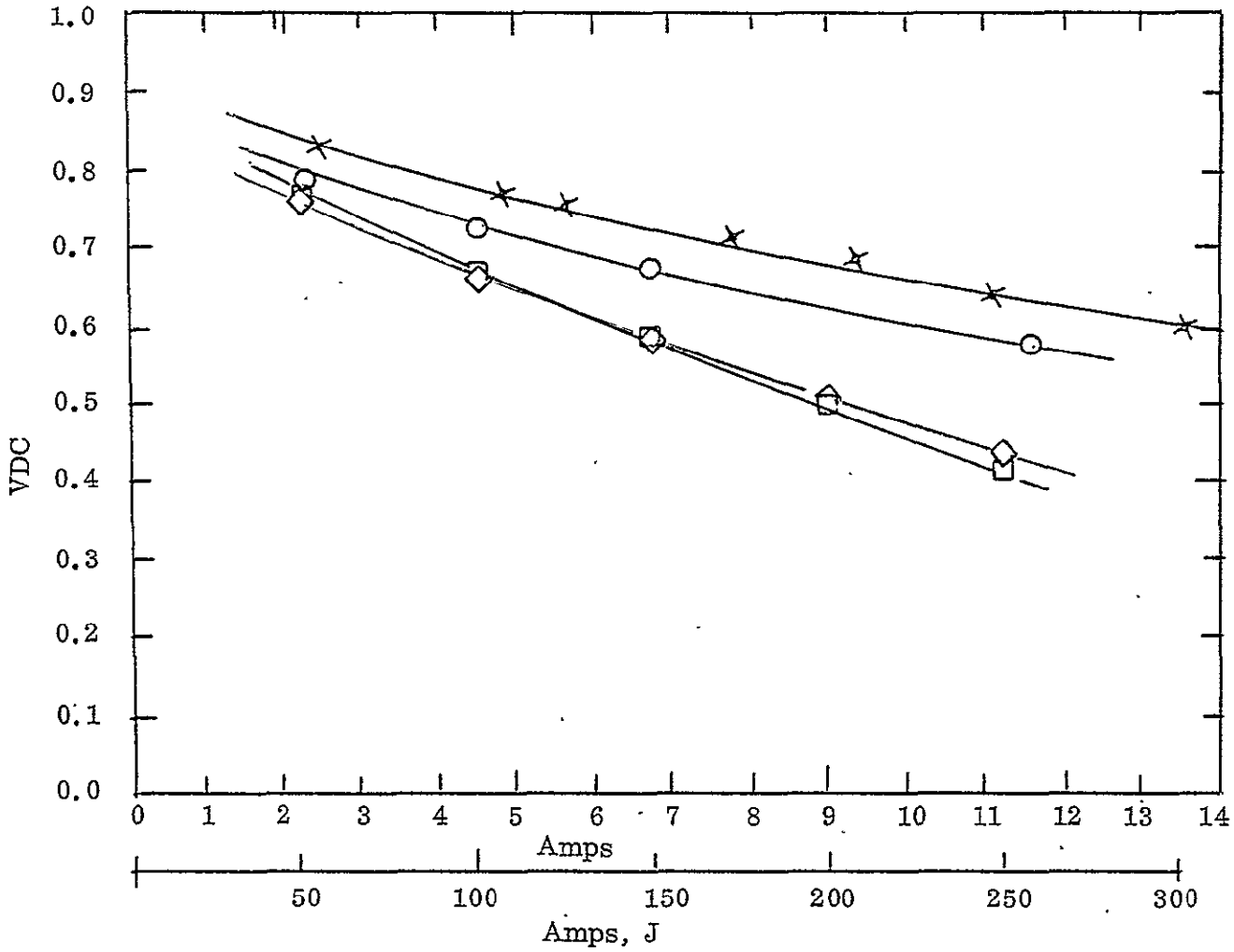
○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-5-6 (B_4C Anode Catalyst Extender)

□ - O_2/H_2 (120°F) R = 0.080 ohm

◇ - O_2/H_2 (165°F) R = 0.070 ohm

Figure 26.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

X - O_2/H_2 (120°F) R = 0.0135 ohm

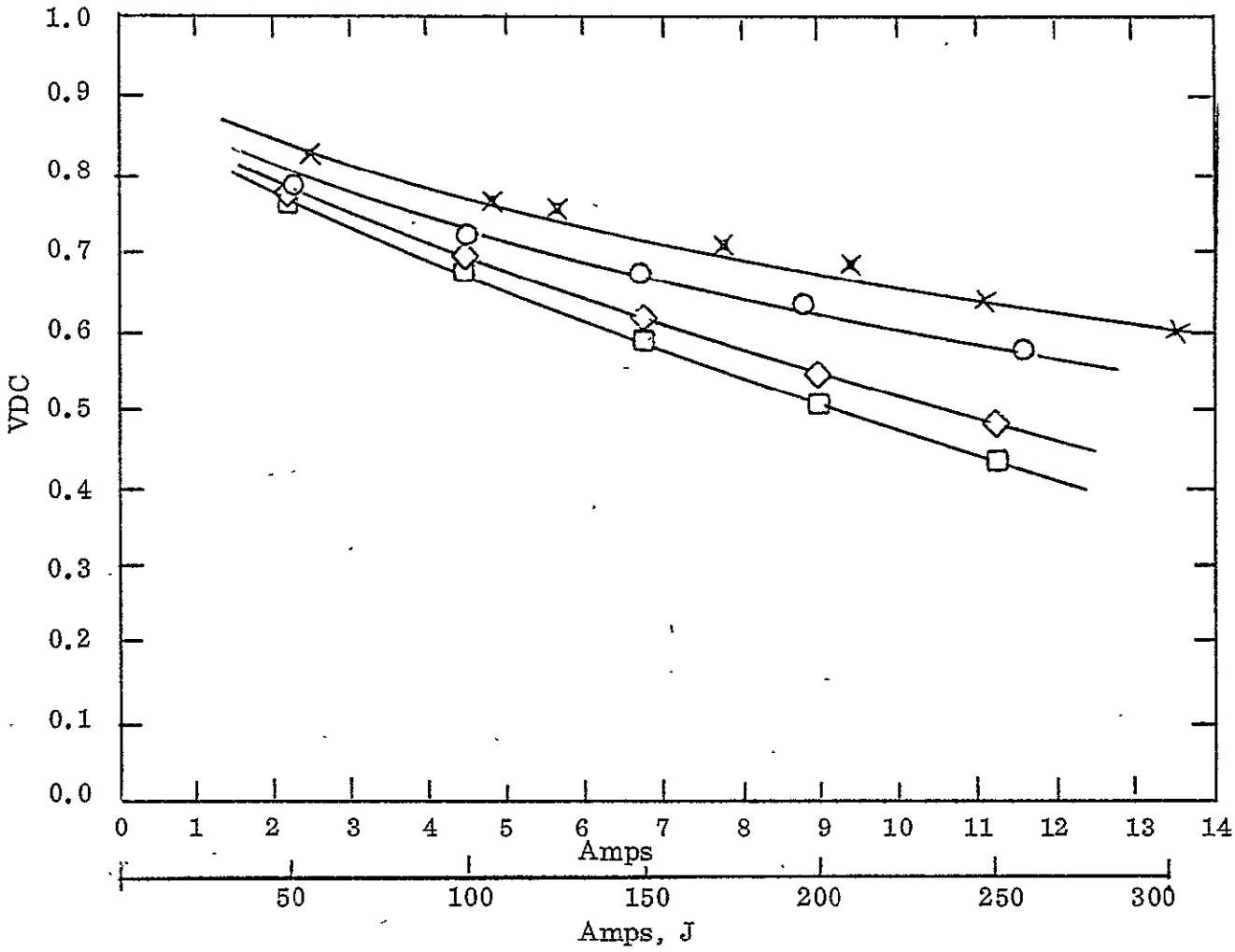
O - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-5-7 (WO_2 Anode Catalyst Extender)

□ - O_2/H_2 (120°F) R = 0.017 ohm

◇ - O_2/H_2 (165°F) R = 0.0135 ohm

Figure 27.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-5-8 (WO_2 Catalyst Extender and T-7 Anode)

□ - O_2/H_2 (120°F) R = 0.015 ohm

◇ - O_2/H_2 (165°F) R = 0.0125 ohm

Figure 28.

- The fuel side gas distribution and current collection configuration was changed from the multiple layers of 3 mil gold screen to a single embossed 3 mil layer of niobium foil.

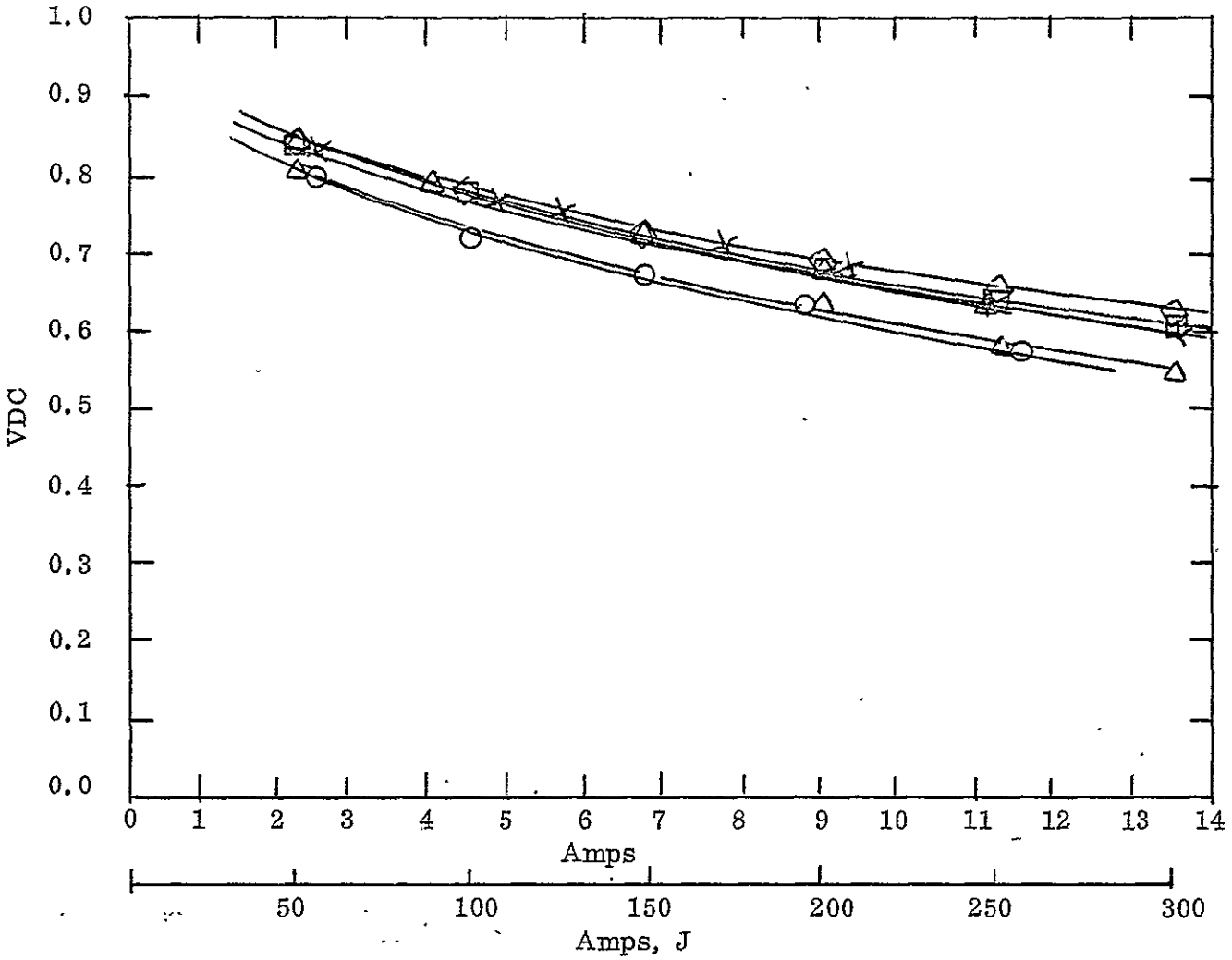
The major impact of the above design modification was in the area of cost reduction. The secondary impact was the tolerance to contaminated fuel.

The two cells fabricated in this subtask are described in Table VII, along with the numerical comparison to the 1974 baseline performance. The performance of cells, shown on Figures 29 and 30, was superior to the 1974 baseline on O_2/H_2 and air/H_2. However, when operation of cell NT-6-1 was attempted on fuel containing 25% CO_2 an unstable performance condition existed. Because this appeared to be a fuel distribution problem, cell NT-6-2 was assembled with the 1974 baseline anode gap configuration with one extra distribution screen. This resultant configuration resulted in very stable contaminated fuel performance (see Figure 31).

TABLE VII

Cell Configurations and Performance Comparison

Fuel Cell Number NASA Technology-Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-6-1	5 mil Nafion [R], niobium cathode screen, anode catalyst 64% PT 21% RU - 15% WO_2 mixed with 15% T-42. Chemplast cathode, niobium fuel distribution plate.	.000	+.015	-.009	+.015
NT-6-2	Same as NT-6-1 except gold screen distribution plate with one extra gold screen.	+.010	+.030	+.006	+.001



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

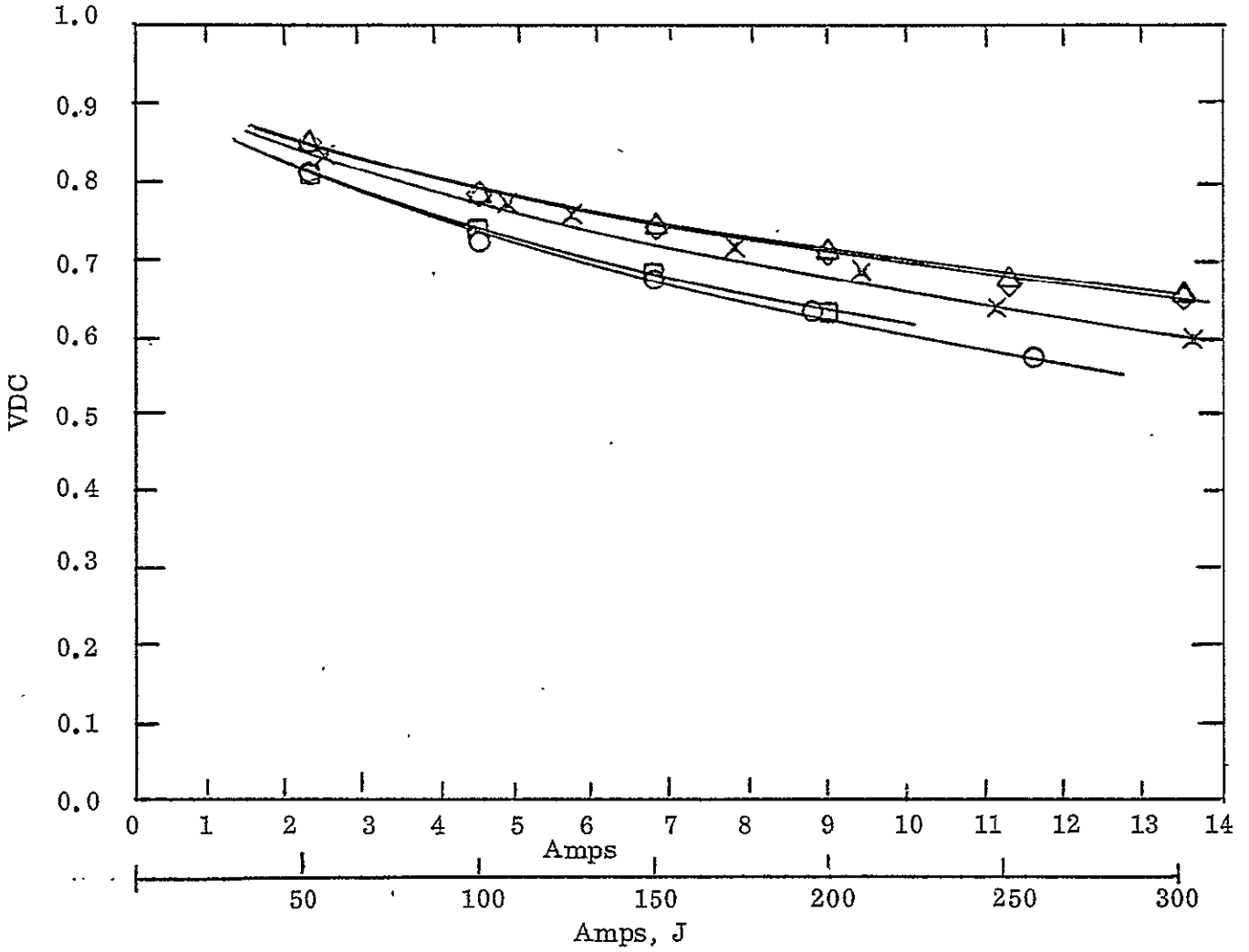
Fuel Cell NT-6-1 (1975 Baseline)

△ - O_2/H_2 (120°F) R = 0.0067 Ohm

◇ - O_2/H_2 (165°F) R = 0.0065 Ohm

□ - Air/H_2 (165°F) R = 0.007 Ohm 2.5 x air stoich

Figure 29.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

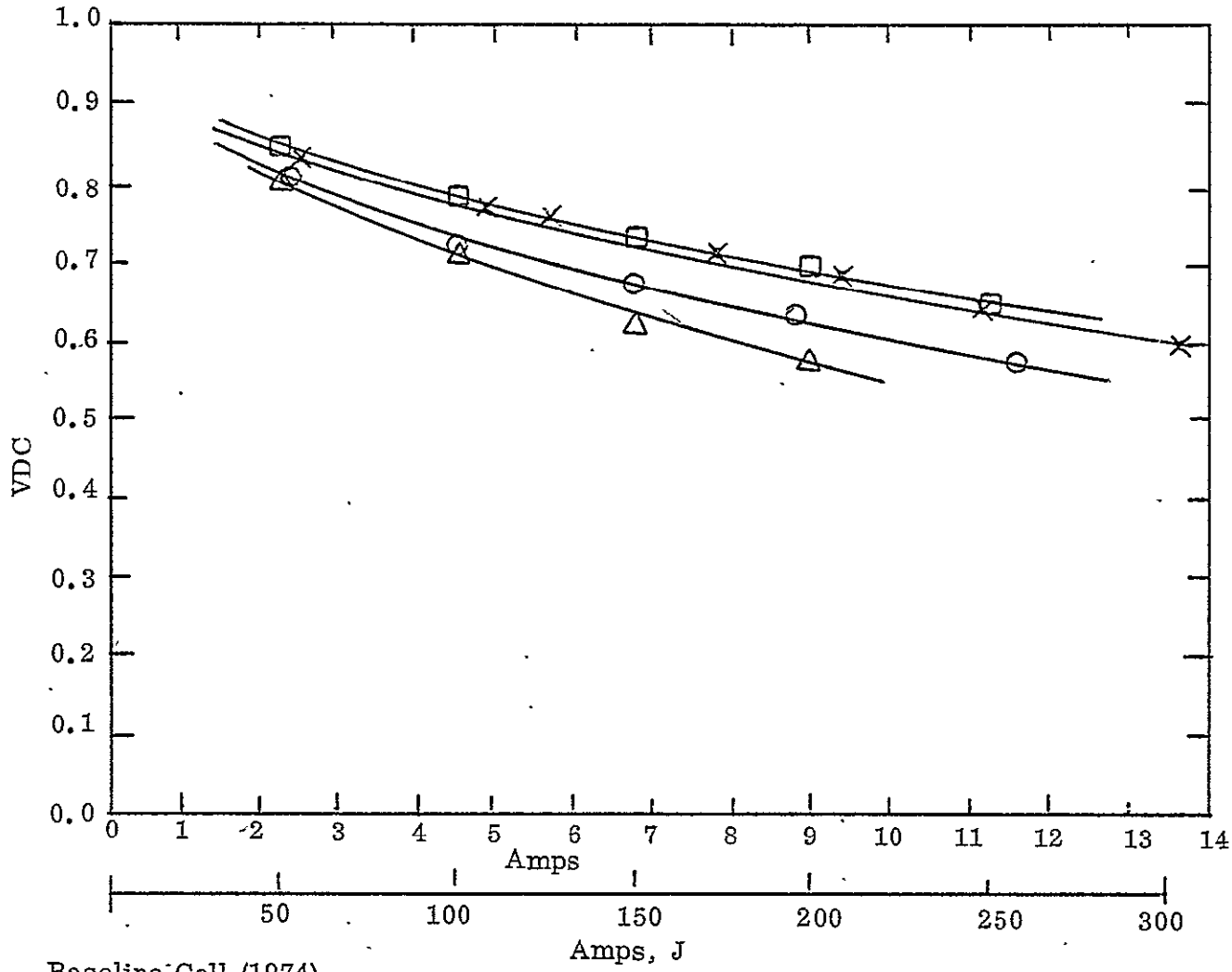
Fuel Cell NT-6-2 (1975 Baseline with Gold Screen Anode)

◇ - O_2/H_2 (120°F) R = 0.0067 Ohm

△ - O_2/H_2 (165°F) R = 0.0065 Ohm

□ - Air/H_2 (165°F) R = 0.007 Ohm
2.5 x Air Stoich

Figure 30.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 Ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 Ohm

Fuel Cell NT-6-2 (1975 Baseline with Gold Screen Anode)

□ - O_2/H_2 (25% CO_2 - 10 PPM CO - 0.3% CH_4 1.25 x stoich (165°F) R = 0.0065 Ohm

△ - O_2/H_2 (25% CO_2 - 0.3% CO - 0.1% CH_4) 1.25 x stoich (165°F) R = 0.0065 Ohm

Figure 31.

3.1.7 Medium Pressure Range Operation

The purpose of this subtask was to evaluate the 1975 baseline configuration at higher temperature and pressure conditions.

The approach taken was to fabricate a cell to the 1975 baseline except to utilize the 1974 anode gap configuration and a 10 mil thick solid polymer electrolyte. Table VIII displays the configuration and numerical performance of the cell.

TABLE VIII

Cell Configurations and Performance Comparison

Fuel Cell Number NASA Technology-Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-7-1	Same as NT-6-2 except 10 mil Nafion ^{R}.	-.029	-.015		

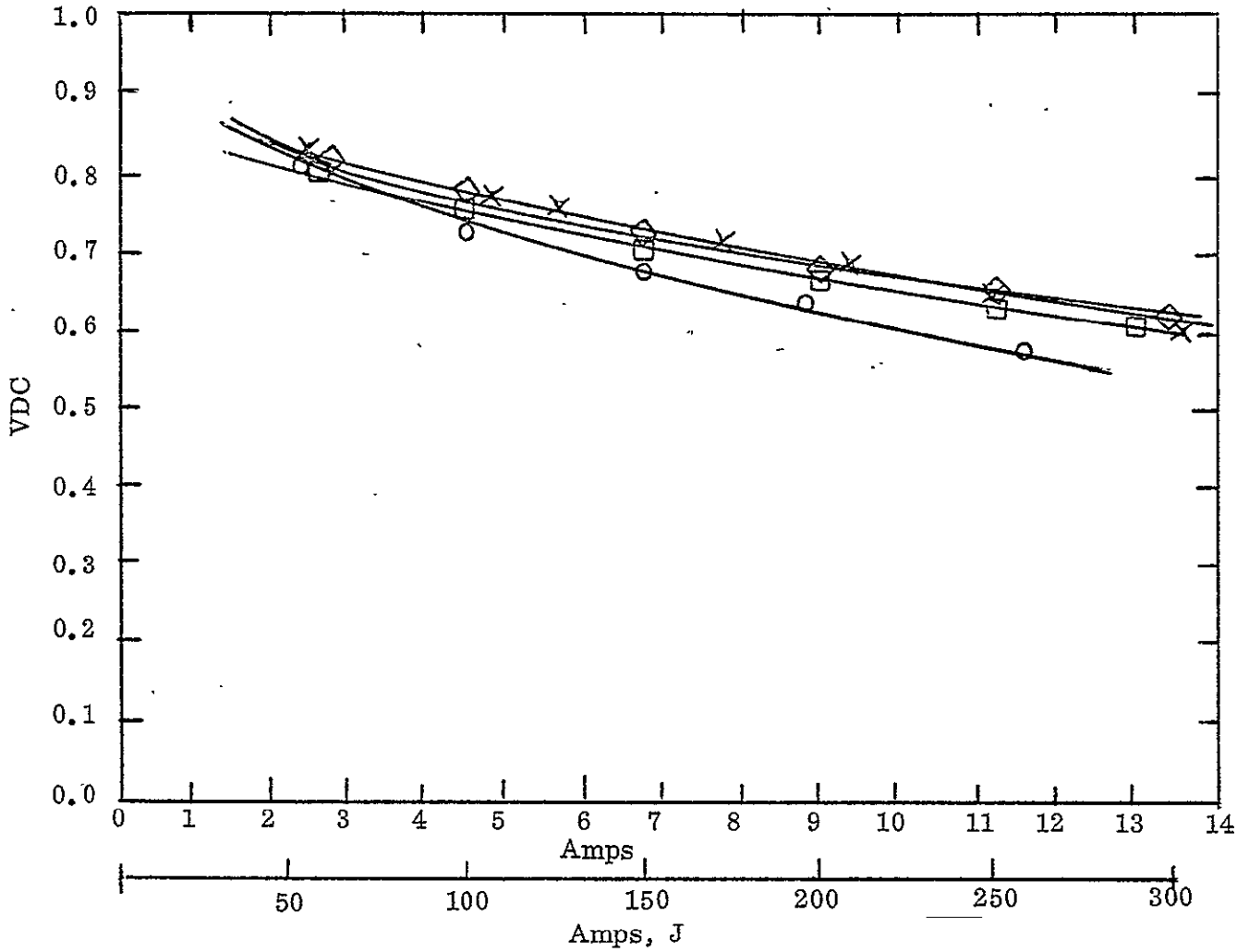
The low pressure performance of cell NT-7-1 is shown on Figure 32. Figure 33 displays the influence of reactant pressure on the performance output of cell NT-7-1. Note the location of the 1973 Space Shuttle technology performance at some 0.06 volt lower at 200 ASF than the 1975 configuration.

Figure 34 exhibits the effect of operation with contaminated fuel, including carbon monoxide, while at 165°F. Note, that the performance on this contaminated fuel is approximately the same as 1973 performance with pure reactants.

The effect of temperature on cell NT-7-1 can be observed on Figure 35 when compared with Figure 34. Increasing the cell operational temperature from 165°F to 220°F has only a slight positive effect on performance on pure reactants. However, performance on contaminated fuel containing carbon monoxide is greatly improved (i.e., considerably above 1973 performance on pure reactants). Figure 35 also shows that a majority of the performance difference between pure and contaminated reactants at 220°F is resultant from the inert masking effect (i.e., 25% CO_2).

3.1.8 Non-Platinized Membrane

The purpose of this subtask was to determine the necessity of membrane platinization when operating with air as the oxidant source.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

Fuel Cell NT-7-1 (1975 Baseline - 10 Mil)

× - O_2/H_2 (120°F) R = 0.0135 ohm

□ - O_2/H_2 (120°F) R = 0.0085 Ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

◇ - O_2/H_2 (165°F) R = 0.0072 Ohm

Figure 32.

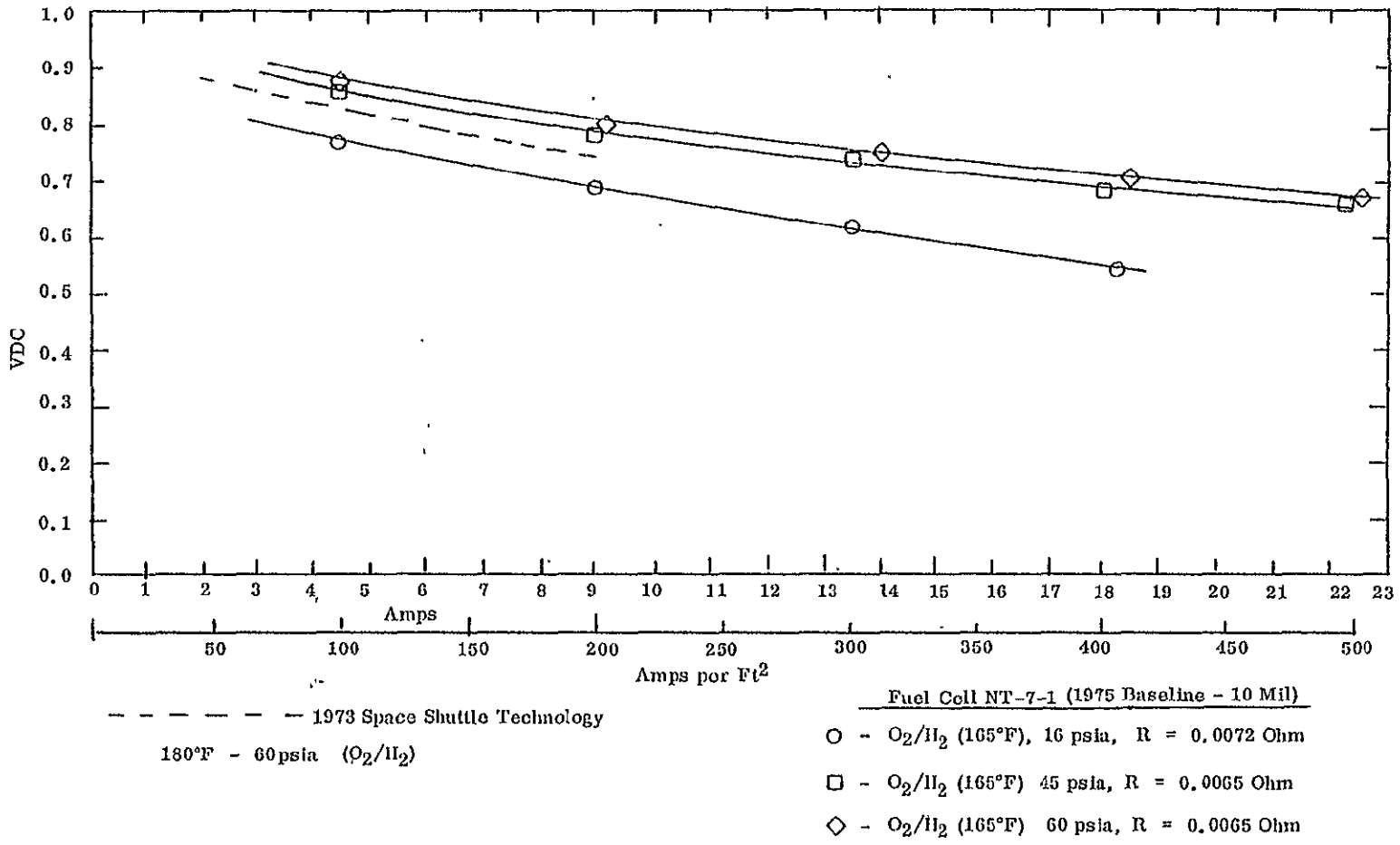
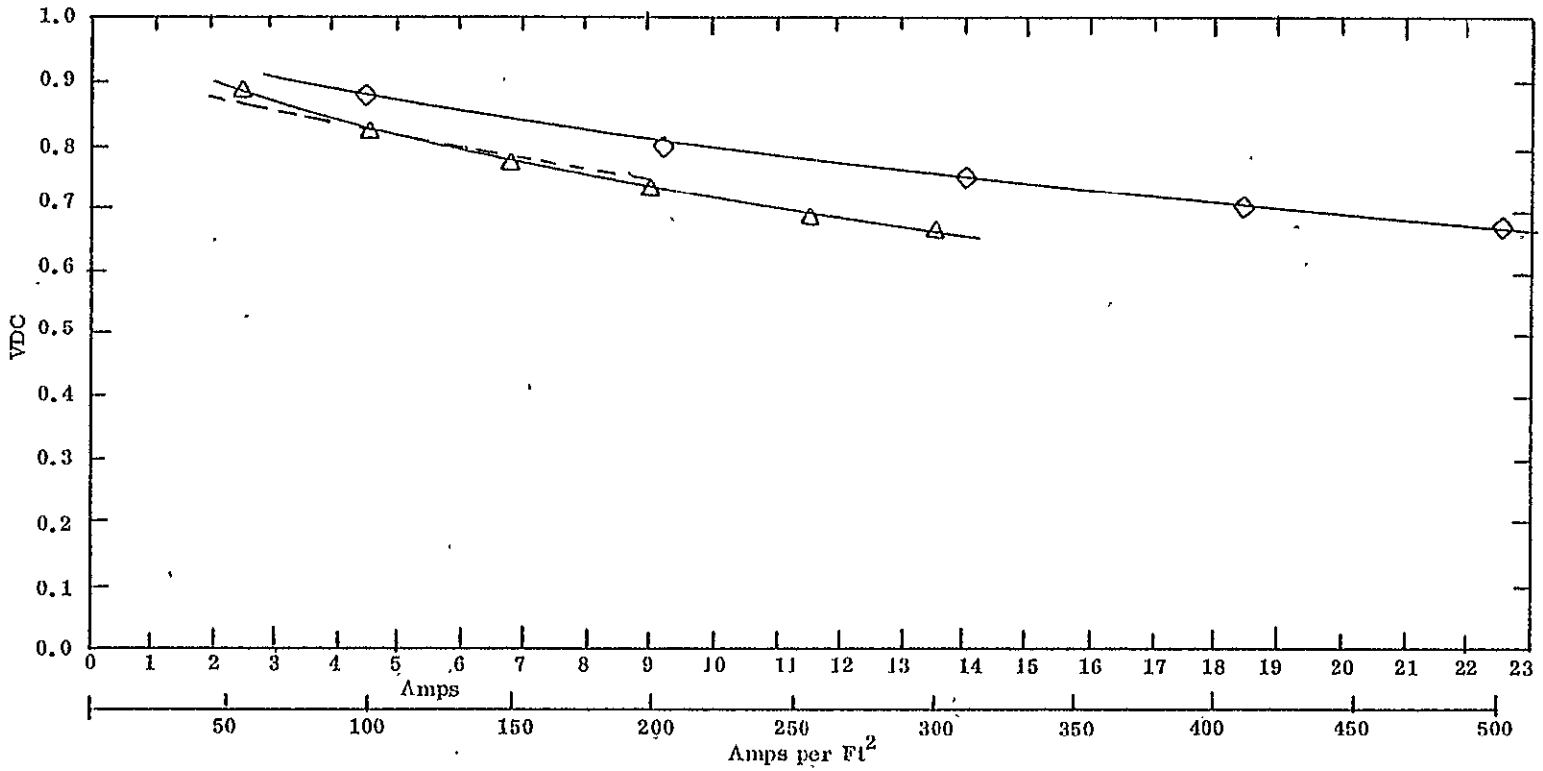

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
VDC
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Amps
50 100 150 200 250 300 350 400 450 500
Amps por Ft2
— — — — — — 1973 Space Shuttle Technology
180°F - 60 psia (O2/H2)
Fuel Cell NT-7-1 (1975 Baseline - 10 Mil)
O - O2/H2 (165°F), 16 psia, R = 0.0072 Ohm
□ - O2/H2 (165°F) 45 psia, R = 0.0065 Ohm
◇ - O2/H2 (165°F) 60 psia, R = 0.0065 Ohm

Figure 33.



– – – – – – – 1973 Space Shuttle Technology

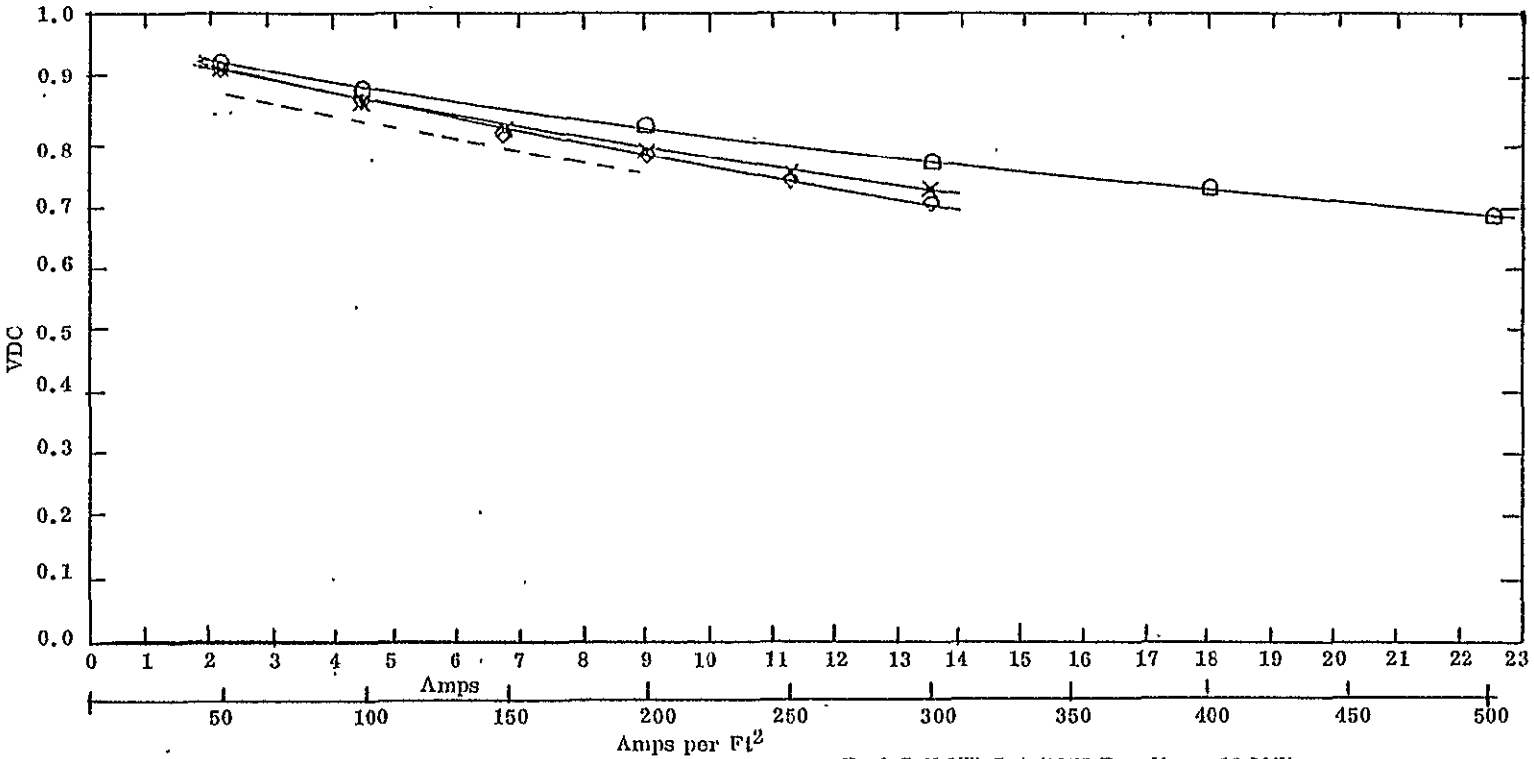
180°F - 60 psia (O_2/H_2)

Fuel Cell NT-7-1 (1975 Baseline - 10 Mil)

◇ - O_2/H_2 (165°F) 60 psia R = 0.0065 Ohm

△ - O_2/H_2 (25% CO_2 - 0.3% CO-0.1% CH_4) 165°F, 60 psia 1.25 x stoich fuel R = 0.0065 Ohm

Figure 34.



- - - - - - - - 1973 Space Shuttle Technology
180°F - 60 Psia (O_2/H_2)

Fuel Cell NT-7-1 (1975 Baseline - 10 Mil)

○ - O_2/H_2 (220°F), 60 psia R = 0.006 Ohm

◇ - O_2/H_2 (25% CO_2 - 0.3% CO-0.1% CH_4) 220°F, 60 psia 1.25 x stoich fuel R = 0.0065 Ohm

× - O_2/H_2 (25% CO_2) 220°F, 60 psia

Figure 35.

During the NASA/JSC technology program of the early seventies, it was shown that the slow degradation of the unplatinized polymer was a function of the partial pressures of the reactants. Since the partial pressures are significantly reduced when operating at near ambient pressure hydrogen and air, it was believed that the polymer platinization was not necessary.

A single cell was fabricated utilizing the unplatinized polymer. Table IX displays the cell configuration summary and the numerical comparison of performance with the 1974 baseline when operated on air and hydrogen.

Table IX

Cell Configuration and Performance

Fuel Cell Number NASA Technology-Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-8-1	Same as NT-6-1 except unplatinized membrane.	N/A	N/A	-.010	+.018

Activation of cell NT-8-1 was performed by the hydrogen side vacuum technique as opposed to electrolysis to preclude the presence of pure oxygen on the cathode side. The cell was then operated for 1500 hours on hydrogen/air at 15 psia (103 kN/m^2) and 16 psia (110 kN/m^2), respectively, and at 165°F (74°C). Performance was normal and stable throughout the test. A product water analysis was performed twice per week to identify the existence of HF which would indicate the degree of any polymer degradation. None of the analyses showed any detectable HF (1 PPM is considered the lower level of detection).

3.1.9 Catalyst Mix Optimization

The purpose of this subtask was to investigate variations in the tungsten oxide to platinum proportions in the anode catalyst relative to operation on fuel contaminated with CO_2 and CO.

In the anode catalyst performance subtask, tungsten oxide was found to significantly reduce the poisoning effect of carbon monoxide. The amount of tungsten oxide utilized in that subtask was arbitrarily selected at the 15% by weight level. The approach taken in this subtask was to fabricate and evaluate cells with a lower and higher proportion of tungsten oxide.

A total of three cells were evaluated in this subtask. Table displays the brief cell description and the numerical comparison to the 1974 baseline performance on O_2/H_2.

Table X

Cell Configuration and Performance

Fuel Cell Number NASA Technology-Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-9-1	Same as NT-6-2 except 7% WO_2 in anode.	-.025	-.002	-	-
NT-9-2	Same as NT-6-2 except 30% WO_2 in anode.	-.039	-.035	-	-
NT-9-3	Same as NT-6-3 except 60% WO_2 in anode.	-.073	-.105	-	-

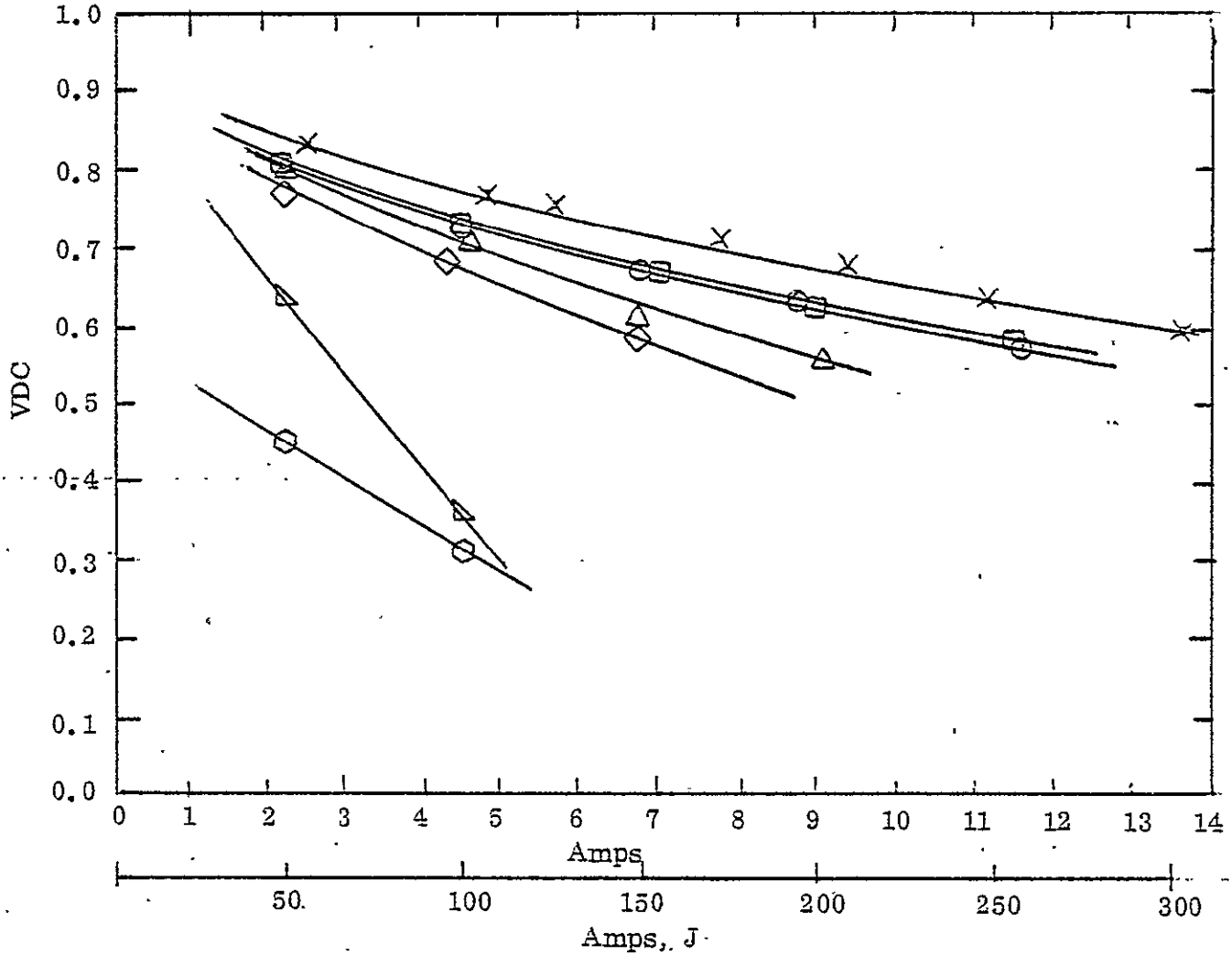
Figure 36 exhibits the resultant performance on each cell on contaminated fuel. The figure shows the performance of the various cells a few hours after changeover to the contaminated fuel. At that point, the lower amount of tungsten oxide would appear to be closer to optimum. However, upon continued operation of the cells, a more rapid performance degradation was noted in the cell containing the least amount of tungsten oxide. (i.e., $\approx$ 0.0007 V/hour loss with 7% WO_2 vs. $\approx$ 0.00035 V/hour loss with 15% WO_2)

3.1.10 Cathode Wetproofing

The purpose of this subtask was to investigate thinner wetproofing material that could potentially result in improved performance.

Chemplast porous film was evaluated as a suitable replacement for the GE/DECP fabricated film during the wetproofing performance subtask. The film thickness utilized in that previously discussed subtask was approximately 7 mils (.1778 mm) (same thickness as the GE/DECP film). The Chemplast material is produced in thinner sheet stock than that previously utilized and thus considered a potential product improvement by reduction of diffusion losses thru the wetproofing.

The approach taken was to fabricate and evaluate a cell utilizing a 2 mil (.0508 mm) wetproofing thickness. Table XI shows the cell NT-10-1 configuration description and comparison performance to the 1974 baseline.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

X - O_2/H_2 (120°F) R = 0.0135 Ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 Ohm

⬡ - O_2/H_2 (25% CO_2 - 0.3% CO-0.1% CH_4) @ 125 stoich (165°F) R = 0.016 Ohm

Fuel Cell NT-6-2 (15% WO_2 Anode)

△ - O_2/H_2 (25% CO_2 - 0.3% CO-0.1% CH_4) @ 1. stoich (165°F) R = 0.0065 Ohm

Fuel Cell NT-9-1 (7% WO_2 Anode)

□ - O_2/H_2 (25% CO_2 - 0.3% CO-0.1% CH_4)@1.25 stoich (165°F) R = 0.0055 Ohm

Fuel Cell NT-9-2 (30% WO_2 Anode)

◇ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4) @ 1.2 stoich (165°F) R = 0.009 Ohm

Fuel Cell NT-9-3 (60% WO_2 Anode)

◺ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4) @ 1.2 stoich (165°F) R = 0.0155 Ohm

Figure 36.

TABLE XI

Cell Configurations and Performance

Fuel Cell Number NASA Technology-Subtask-Cell NT - X - X	Deviation from Baseline Fuel Cell	Performance Variance from 1974 Baseline Fuel Cell			
		O_2/H_2 100 ASF at 120°F VDC (0.775)	O_2/H_2 200 ASF at 120°F VDC (0.680)	Air/H_2 100 ASF at 165°F VDC (0.730)	Air/H_2 200 ASF at 165°F VDC (0.625)
NT-10-1	Same as NT-6-1 except 2 mil Chemplast 4 Pt anode.	-.025	-.020	-.030	-.105

Figure 37 displays initial cell performance and 140th hour performance. Although initial performance on both O_2/H_2 and air/H_2 was below normal, a steady improvement of the O_2/H_2 performance with time was noted. No improvement with time was observed for the air/H_2 operation.

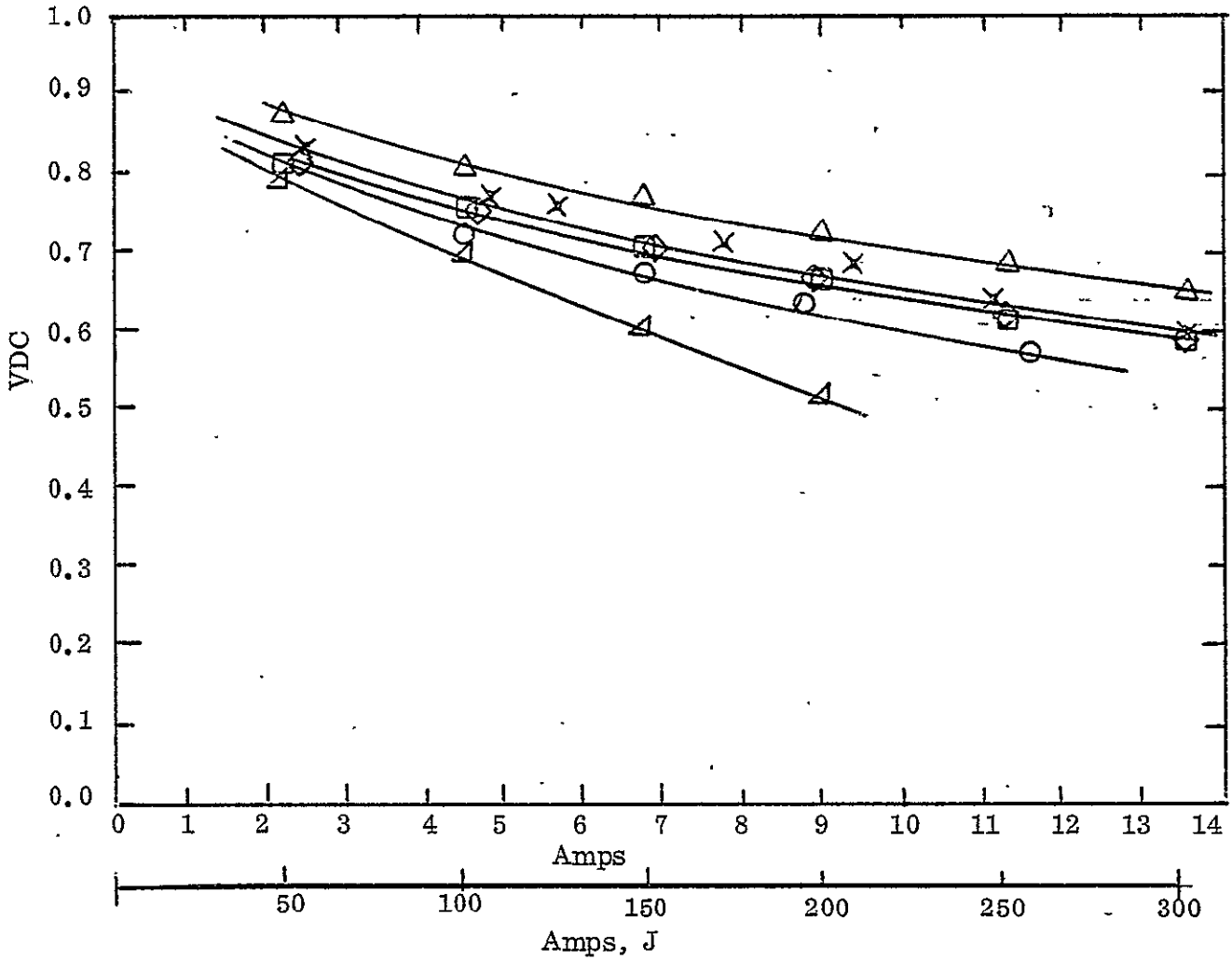
3.1.11 Electrode Manufacturing Techniques

The purpose of this subtask was to identify and evaluate "non-standard" electrode configurations so as to reduce the quantity of noble metal required in the electrodes.

The approach taken for this subtask was to conduct a series of design/technology reviews.

The catalyst mix utilized on the anode of cell NT-5-6 contained 4 mg/cm^2 metal loading of which .2 mg/cm^2 was platinum with the balance being boron carbide. Work performed in 1964 during the General Electric direct hydrocarbon fuel cell program showed that platinum deposited on boron carbide gave excellent performance when operated as an anode in a liquid acid fuel cell. Performance at a platinum loading of .16 mg/cm^2 on boron carbide was comparable to pure platinum catalyst at 45 mg/cm^2.

During the latter part of this program phase, a plan was devised from the design/technology reviews by which the success shown on the liquid acid cell could be transferred to the solid polymer electrolyte technology. This plan calls for a repeat fabrication and evaluation of the aforementioned electrode configuration in the liquid acid cell. Upon success of this activity, a transfer of the techniques to the solid polymer electrolyte technology will be performed.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-10-1 (2 Mil Chemplast)

□ - O_2/H_2 (120°F) R = 0.009 Ohm

◇ - O_2/H_2 (165°F) R = 0.0085 Ohm Initial Run

△ - O_2/H_2 (165°F) R = 0.008 Ohm 140 Hours After Start

◁ Air/H_2 (165°F) R = 0.008 Ohm Initial and at 140 Hours

Figure 37.

3.1.12 Extended Endurance Testing

The purpose of this subtask was to identify the long term effects of operating on a fuel contaminated with carbon monoxide among other contaminants.

The approach taken was to utilize cell NT-1-9, fabricated and evaluated under the anode catalyst performance subtask, for continued endurance testing. Figure 38 displays the first long term run on contaminated fuel from the 306th hour to the 570th hour. During the course of that run a slow rate of voltage decay was noted. At the end of the run a switchover to pure hydrogen was accomplished and a complete recovery to initial O_2/H_2 performance levels was observed.

To assess the effect of operational temperature on the special anode catalyst tolerance to the carbon monoxide poisoning, the cell temperature was reduced to 130°F (54°C). Figure 39 displays the resultant performance on the contaminated fuel. As can be observed on the figure, a large decay in voltage indicated the rather large influence the temperature plays in the ability to operate on fuel contaminated with carbon monoxide. A switch back to pure hydrogen resulted in complete recovery to initial O_2/H_2 performance levels.

Figure 40 displays the final long-term contaminated fuel run which was followed once again by complete recovery to initial O_2/H_2 levels when switchover was conducted.

Figure 41 is a time plot which shows the degradation trends during each of the three runs.

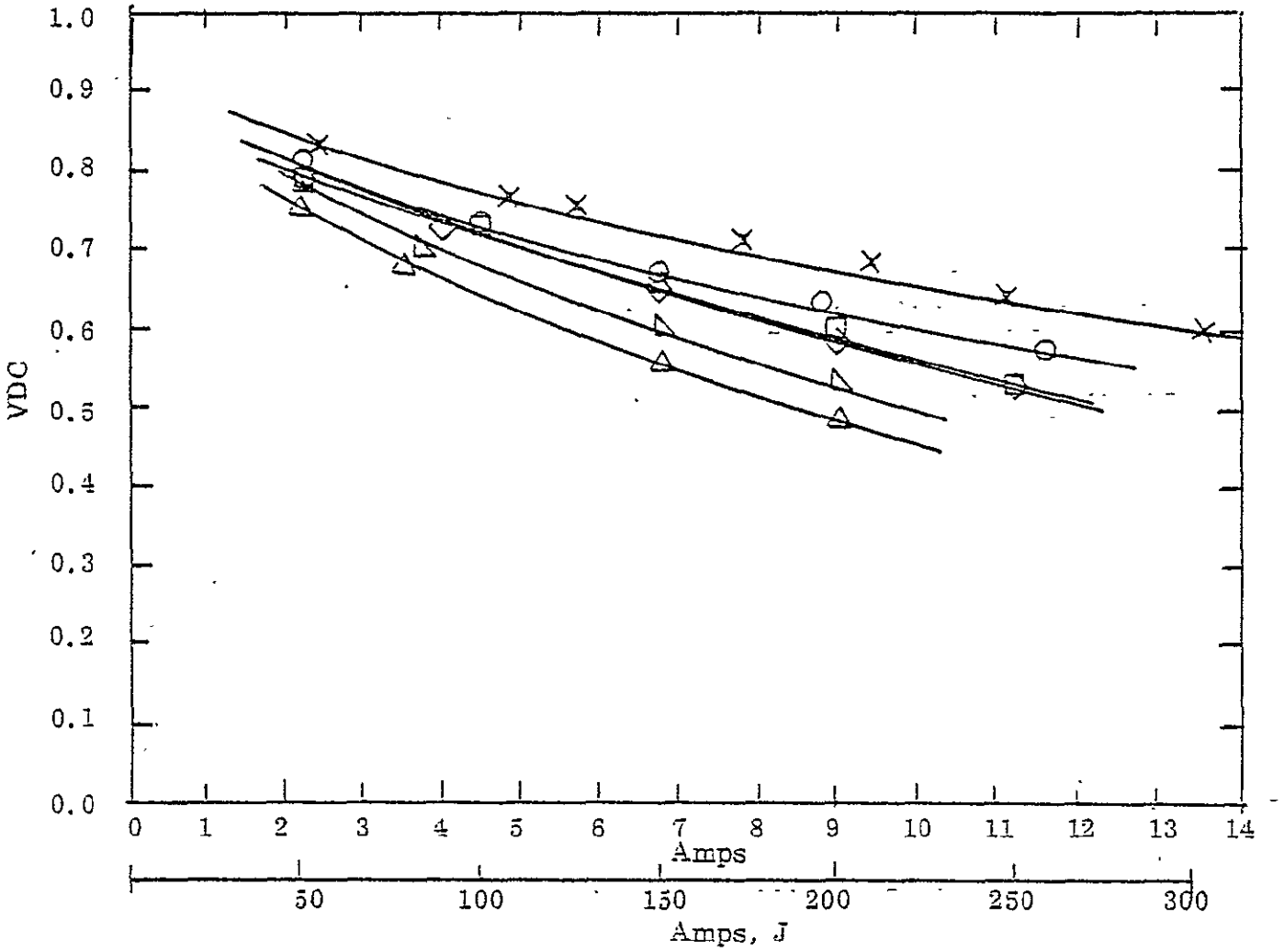
3.2 Development Cell Fabrication

The purpose of the second major task was to design and fabricate a full-scale cell capable of operating on pure or contaminated fuel and pure oxygen or air. The design of this hardware was to incorporate a maximum of demonstrated advancements out of the subscale laboratory evaluations.

3.2.1 Development Cell Design

The desired characteristics of the cell were established based on the laboratory evaluation results, readily available material sizes, and previous assembly experience. These characteristics are displayed on Table XII.

In order to finalize the configuration of the various flow passages such that desired ΔP's could be maintained, a series of bench tests were performed. A flow test fixture was fabricated which could simulate the flow and differential pressures desired. Figure 42 exhibits the bench test set-up.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-1-9 (15% WO_2 - 21% Ru Anode)

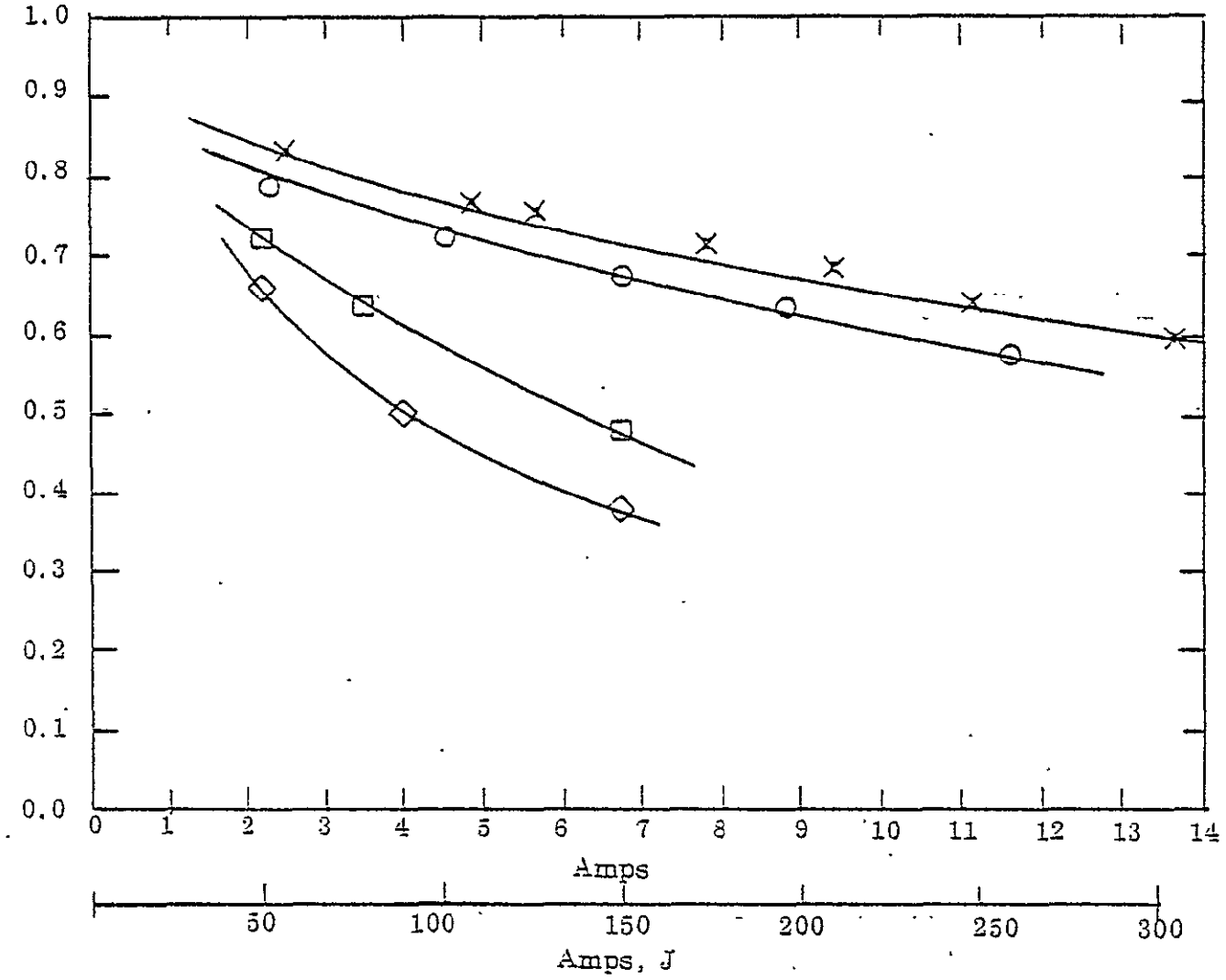
□ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4) @ 1.25 stoich (165°F) R = 0.008 ohm - 6 hours after switchover - 312 total hours of operation

◇ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4) @ 1.25 stoich (165°F) R = 0.008 ohm - 330 total hrs operation

△ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4) @ 1.25 stoich (165°F) R = 0.008 ohm - 426 total hrs operation

△ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4) @ 1.25 stoich (165°F) R = 0.0075 ohm - 570 total hours operation

Figure 38.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

⊠ - O_2/H_2 (120°F) R = 0.0135 ohm

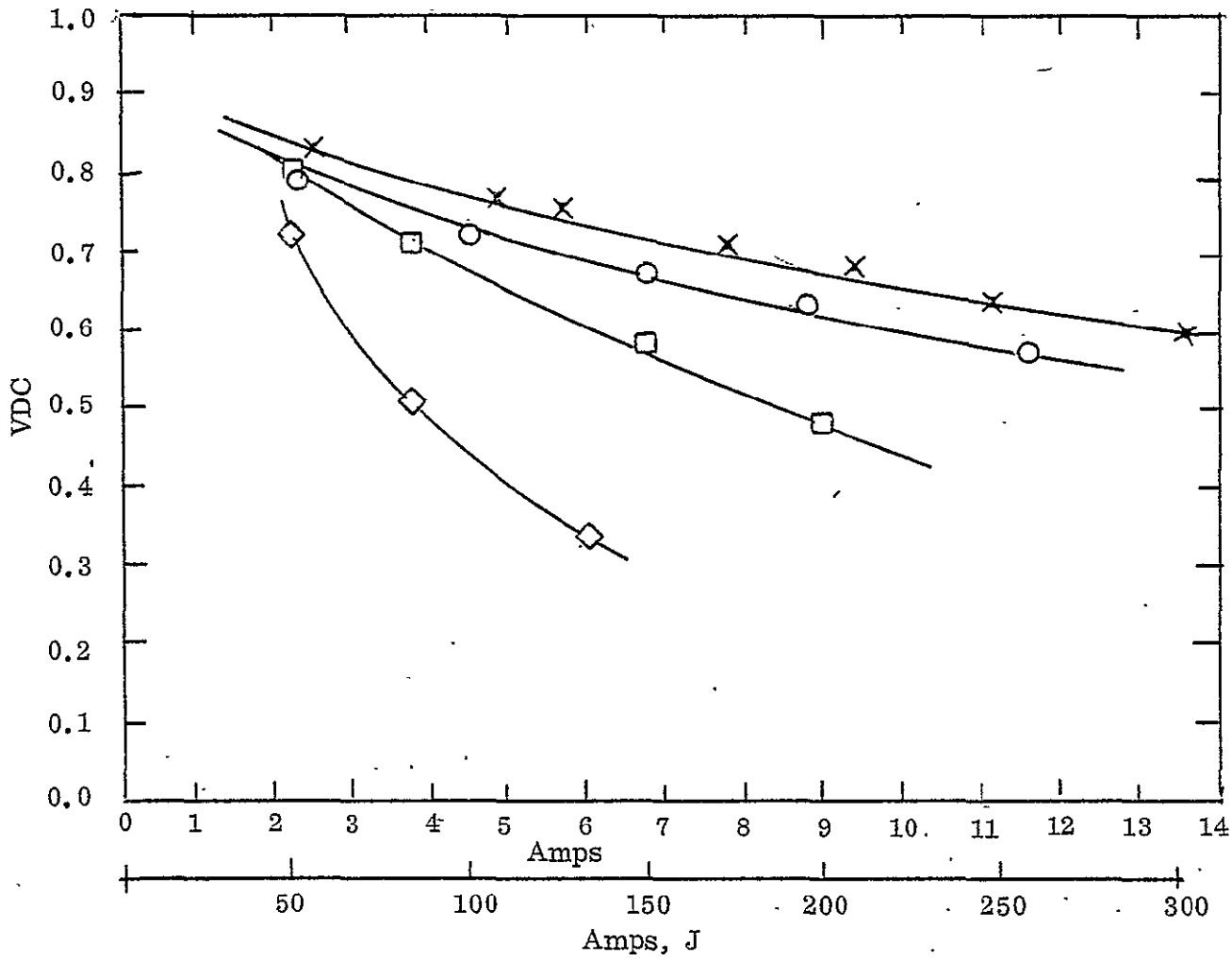
○ - Air/H_2 (165°F) 2.5 x air stoich flow
R = 0.0126 ohm

Fuel Cell NT-1-9 (15% WO_2 - 21% Ru Anode)

□ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4) @ 1.25 stoich (130°F) R = 0.0085 ohm - 24 hours after switchover 666 total hours of operation

◇ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4) @ 1.25 stoich (130°F) R = 0.0085 ohm - 800 hours of operation

Figure 39.



Baseline Cell (1974)

Cathode Pressure - 35" H_2O
Anode Pressure - 15" H_2O

× - O_2/H_2 (120°F) R = 0.0135 ohm

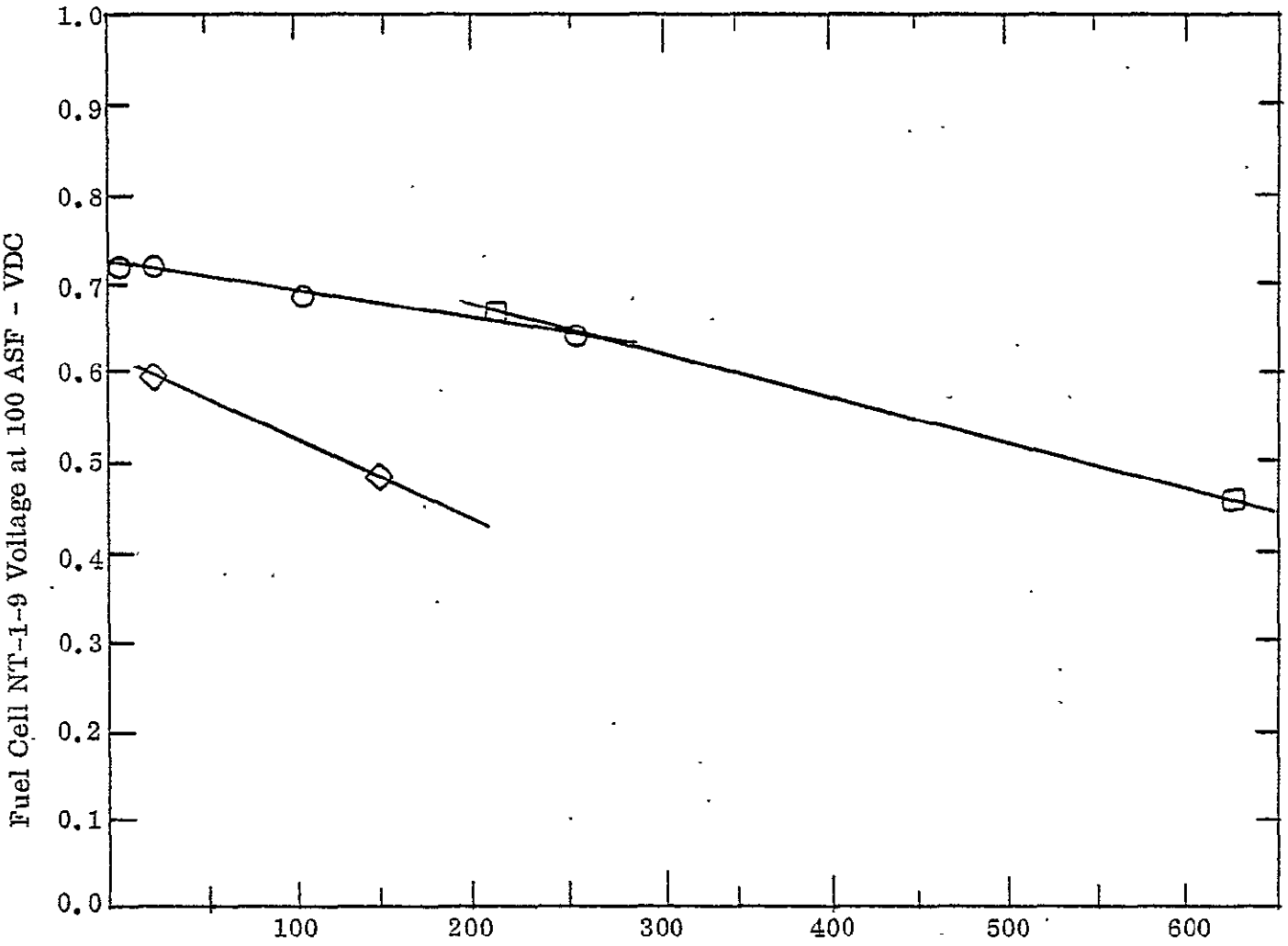
○ - Air/H_2 (165°F) 2.5 x air stoich flow R = 0.0126 ohm

Fuel Cell NT-1-9 (15% WO_2 - 21% Ru Anode)

□ - O_2/H_2 (25% CO_2-0.3% CO-0.1% CH_4)@ 1.2 stoich (165°F) R = 0.008 ohm - 1170 total hours of operation (216 hours after switchover)

◇ - O_2/H_2 (25% CO_2 - 0.3% CO-0.1% CH_4)@ 1. stoich(165°F) R = 0.008 ohm - 1578 total hours of operation

Figure 40.



○ - 1st Run (306-570 hours)
(165°F) (16 psia O_2)

◇ - 2nd Run (642-800 hours)
(130°F) (16 psia O_2)

□ - 3rd Run (954-1578 hours)
(165°F) (16 psia O_2)

Figure 41.

Table XII

Development Cell Design

Cell Characteristics at Design Point

Active Area	0.7 Ft^2 (650 cm^2)
Current Density	250 ASF (2.7 amps/cm^2)
Heat Rejection	526 Btu/Hr
O_2 Consumption	655 cc's/Min
O_2/Air Inlet Pressure	35" (88.8 cm) H_2)
Air Flow @ 2.5 x Stoich	8 Liter/Min
O_2/Air ΔP	10" (25.4 cm) @ 4 x Stoich
H_2 Consumption	1310 cc/Min
Fuel Inlet Pressure	15" (38 cm) H_2O
Fuel Flow (75% H_2) @ 1.25 x Stoich	2190 cc/Min
Fuel ΔP	10" (25.4 cm) H_2O (Max) @ 1.5 x Stoich
Coolant Inlet Temperature	160°F (71°C)
Coolant Inlet Pressure	25" (63 cm) H_2O
Coolant Flow	400 cc/Min
Coolant ΔP	20" (51 cm) H_2O

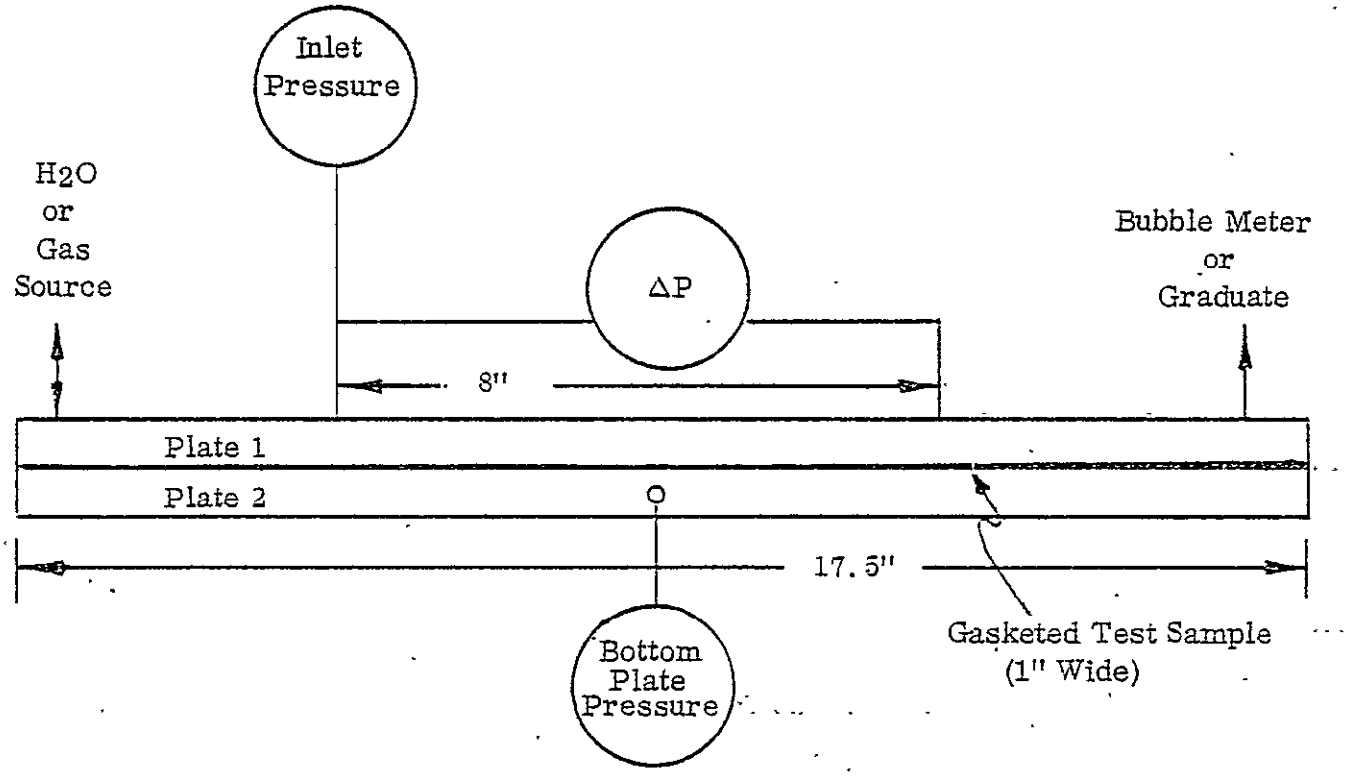


Figure 42. Flow Test Set-Up

A total of eleven configurations were evaluated either on water or gas. Table XIII displays the flow test results for each of the configurations.

Configuration #1 was selected for the coolant passage and configuration #9 for the fuel passage. Flow characteristics were the primary criterion for configuration selection although ease of fabrication and costs had minor impacts. The cathode passage was selected to be a so-called "open gap" and as such the flow would be controlled by inlet and outlet restrictors.

There was concern regarding the fuel side configuration. The concern was that increased resistance would exist between the electrolyte and the fuel side separator plate because of the small point contacts. A sample of the selected fuel side configuration was fabricated for use with the 3 x 3 laboratory hardware. Laboratory size cell NT-2-1, which was operating with a standard 1974 baseline gold screen assembly for fuel flow, was discharged, disassembled and the new embossed niobium fuel plate configuration installed. Figure 43 displays the resultant performance as compared to the baseline fuel side configuration. The performance comparison showed the configurations to be within 0.01 volt at all load points.

The major features incorporated into the design from the subscale laboratory activities included:

- Bi-polar current collection
- Niobium cathode screen
- Alloy anode catalyst (Pt-21 Ru - 15 WO_2)

Other demonstrated advances were not considered sufficiently proven by the design decision date such that incorporation was not attempted. These advances included:

- Reduced thickness electrolyte
- Low cost Chemplast wetproofing
- Simplified membrane processing

Engineering design sketches of the cell and stack were presented to NASA/JSC personnel during a design review on December 17, 1974.

3.2.2 Development Cell Fabrication

Fabrication of the hardware to the engineering design sketches was accomplished without difficulty with one exception. The cathode side separator plate was to be die drawn from a 3 mil (.0762 mm) thick niobium sheet. The maximum draw desired was fabricated into a small sample die. Test fabrications with unannealed 3 mil niobium sheet stock produced the desired quality draw. A full scale die was then fabricated and full width niobium sheet stock ordered. The sheet stock was ordered fully annealed

TABLE XIII

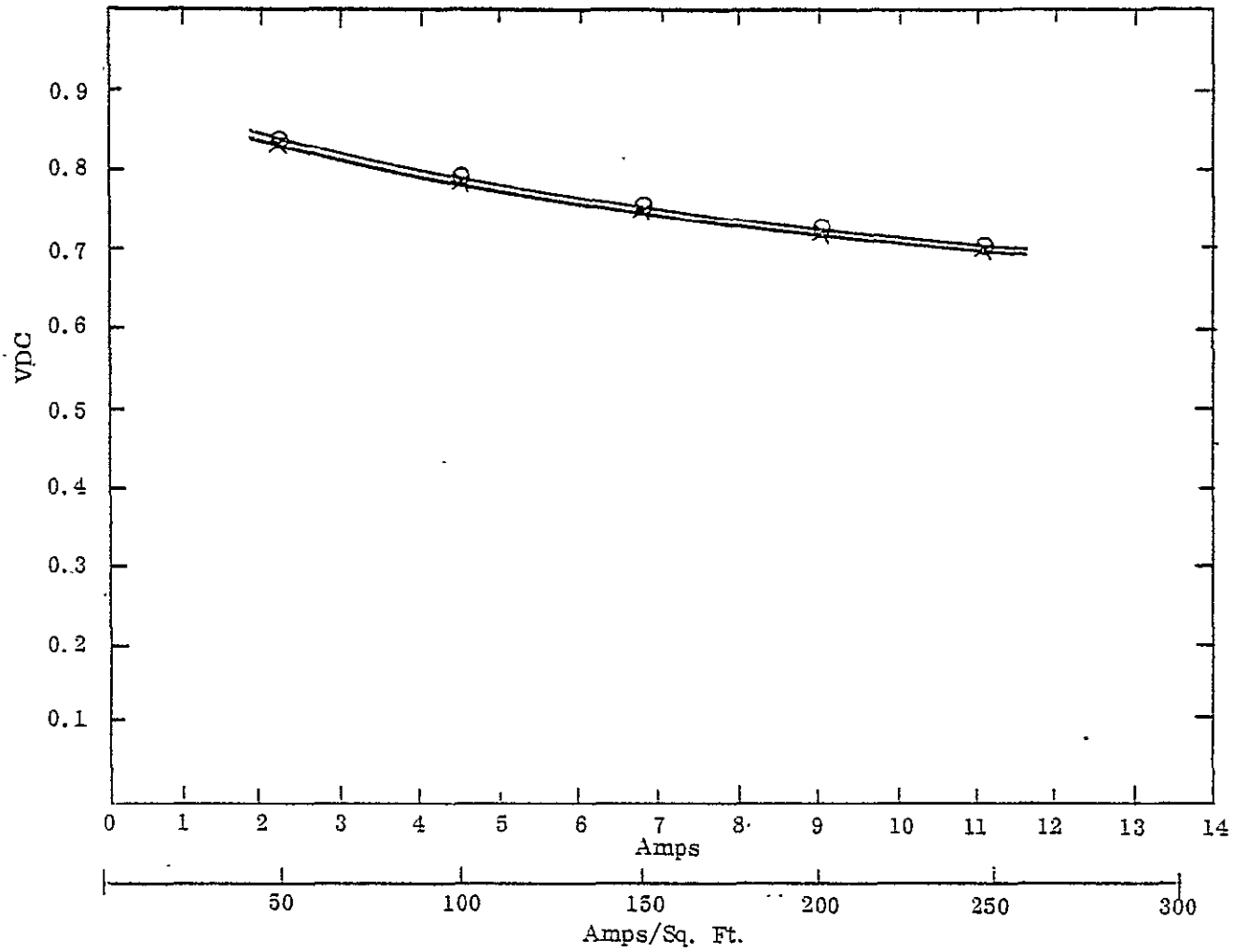
NASA Technology Fuel Cell Flow Test Configurations

Configuration	Inlet Press. "H_2O	Δ Press. "H_2O	Bottom Plate Press. "H_2O	H_2O Flow cc/min	Gas Flow cc/min
1. Nettlon Screen 0.023"	35	21	35	75	-
Polyethelene 11 mesh/in.	29	18	35	70	-
□ ⟶ Flow Direction	23	13	35	58	-
Between - 3 mil Nb Foil	19	10	35	51	-
2. Same as 1.	23	13	35	61	-
Except ◇ Flow ⟶	38	21	35	91	-
	20	11	35	54	-
3. 3 mil Nb Foil	20	11	35	57	-
with Impression from	24	12	35	67	-
10 mil 2 Ø Ti Screen	38	21	35	120	-
Pressed at 160 Ton	25	13	35	70	-
Average Ht. 0.012"	42	19	35	116	-
◇ ⟶ Flow	5	2.5	35	-	545 } O_2
	10	5.0	35	-	1200 } O_2
	15	8.0	35	-	1715 } O_2
4. Same as 3.					
Except with 11 mil	5	3	35	-	400 } O_2
Membrane Covering Flow	10	6.5	35	-	923 } O_2
Area of ΔP Measurement	15	9.5	35	-	1500 } O_2
5. Same as 3.	25	16	35	54	-
Except ◇ ⟶ Flow	40	25	35	98	-
6. Same as 3.					
Except 80 Ton Press	27	13	35	60	-
Average Ht. 0.008"	41	19	35	100	-
7. Same as 3.					
Except 20 mil 2 Ø Ti	26	14	35	53	-
Screen at 160 Ton	42	20	35	86	-
Average Ht. 0.016" ◇ ⟶ Flow					
8. Same as 5. Except 20 mil Deep	4	3	35	-	240 } N_2
Channel Along One Side at	10	7	35	-	625 } N_2
Screen Impression - Flow Area	15	10	35	-	1000 } N_2
of ΔP Measurement Covered					
with 11 mil Membrane					

TABLE XIII (Continued)

NASA Technology Fuel Cell Flow Test Configurations

	Configuration	Inlet Press. "H_2O	Δ Press. "H_2O	Bottom Plate Press. "H_2O	H_2O Flow cc/min	Gas Flow cc/min	
9.	Same as 5. Except	5.2	4.5	35	-	220	
	Flow Area of ΔP Measurement	10	9	35	-	440	N_2
	Covered with 11 mil Membrane	15	13	35	-	650	
10.	Same as 4. Except	35	31	35	21	-	
	80 Ton Press	53	52	35	31	-	
	Average Ht. 0.008"	88	82	35	24	-	
		Impossible to remove air bubbles in flow path.					
11.	Same as 10. Except	25	25	35	0	-	
	Upside Down Installation	100	100	35	0	-	
	Pertaining to Screen Impression	No water flow possible.					



Cell NT-2-1 (5 mil Nafion ®)

O - O_2/H_2 (165° F) Au Screen Anode

× - O_2/H_2 (165° F) Niobium Plate Anode

Figure 43.

so as to provide further assurance that the draw could be successfully accomplished. Test draws utilizing the unannealed stock, only two-thirds the required width, on the full size die, produced acceptable parts. When the fully annealed material was attempted an uncracked part was unable to be formed in up to ten trials. The purchase and trial of full width unannealed niobium sheet stock resulted in no improvement. In order to keep the schedule and maintain the intent of the design, the acceptable deep draw ribs were cut from the narrower material and welded to the unformed full width sheet stock.

The fabrication of the hardware continued without further incident. Figures 44 thru 46 display the various stages of the cell assembly.

The completed cell assembly and a second half cell (containing oxidant and coolant chambers only) were assembled into fuel cell stack NT-01 (see Figure 2). Leakage, flow and electrical shorting checks were found normal on the completed stack. The 1000 Hz impedance of the cell in the stack hardware was found to be slightly higher than expected (0.005 ohm vs. < 0.003 ohm). It is probable that one or both of the following conditions contributed to this observation:

The anode electrode, not containing an integral current collector screen, will undoubtedly make better electrical contact with the embossed anode current collector plate under the normal operational temperature and differential pressure conditions.

The compression of the stack at the central contact areas (along the cathode ribs) may be slightly less than desired. This situation may be correctable by either the addition of central area shimming (.005" to .010") (.1270 to .2540 mm) or by thermal expansion of the components during normal operation.

It is planned that the stack be operated before any shimming is performed. The operation of the stack will add to the insight as to the cause of the slightly high impedance and allow determination as to whether shimming is required.

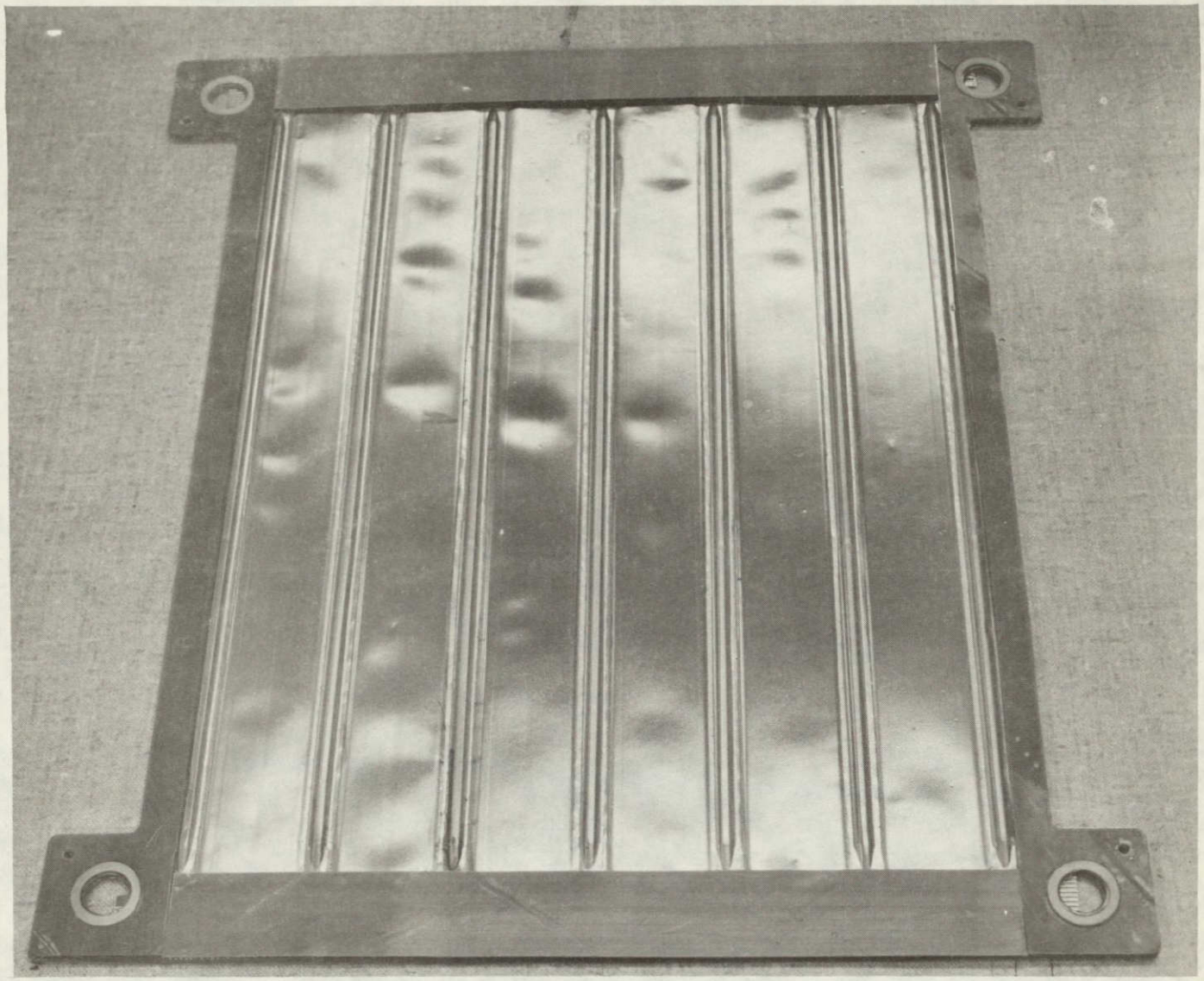


Figure 44. Anode/Cathode Collector Plate Assembly (Cathode Side)

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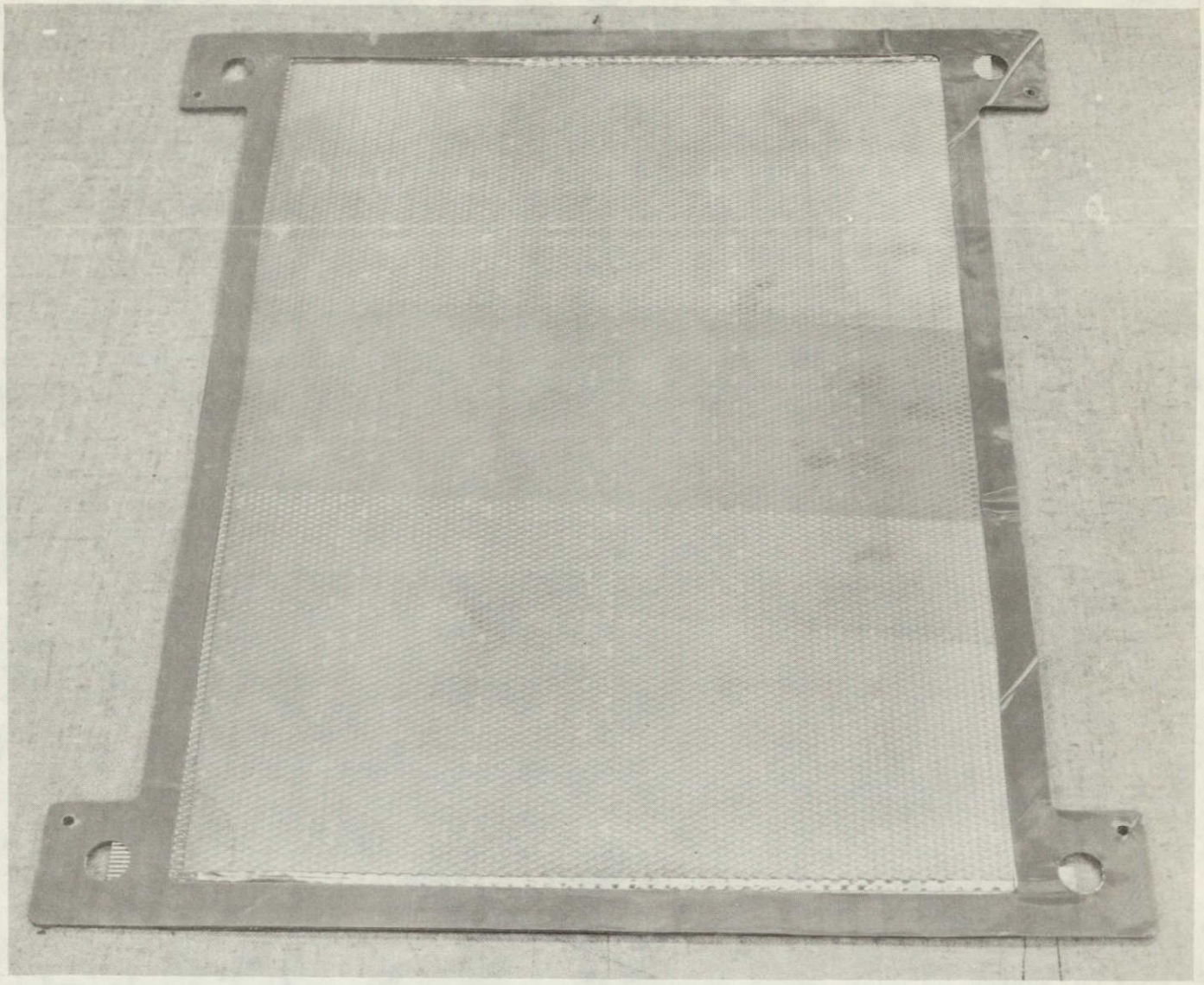

Figure 45. Anode/Cathode Collector Plate Assembly (Anode Side)

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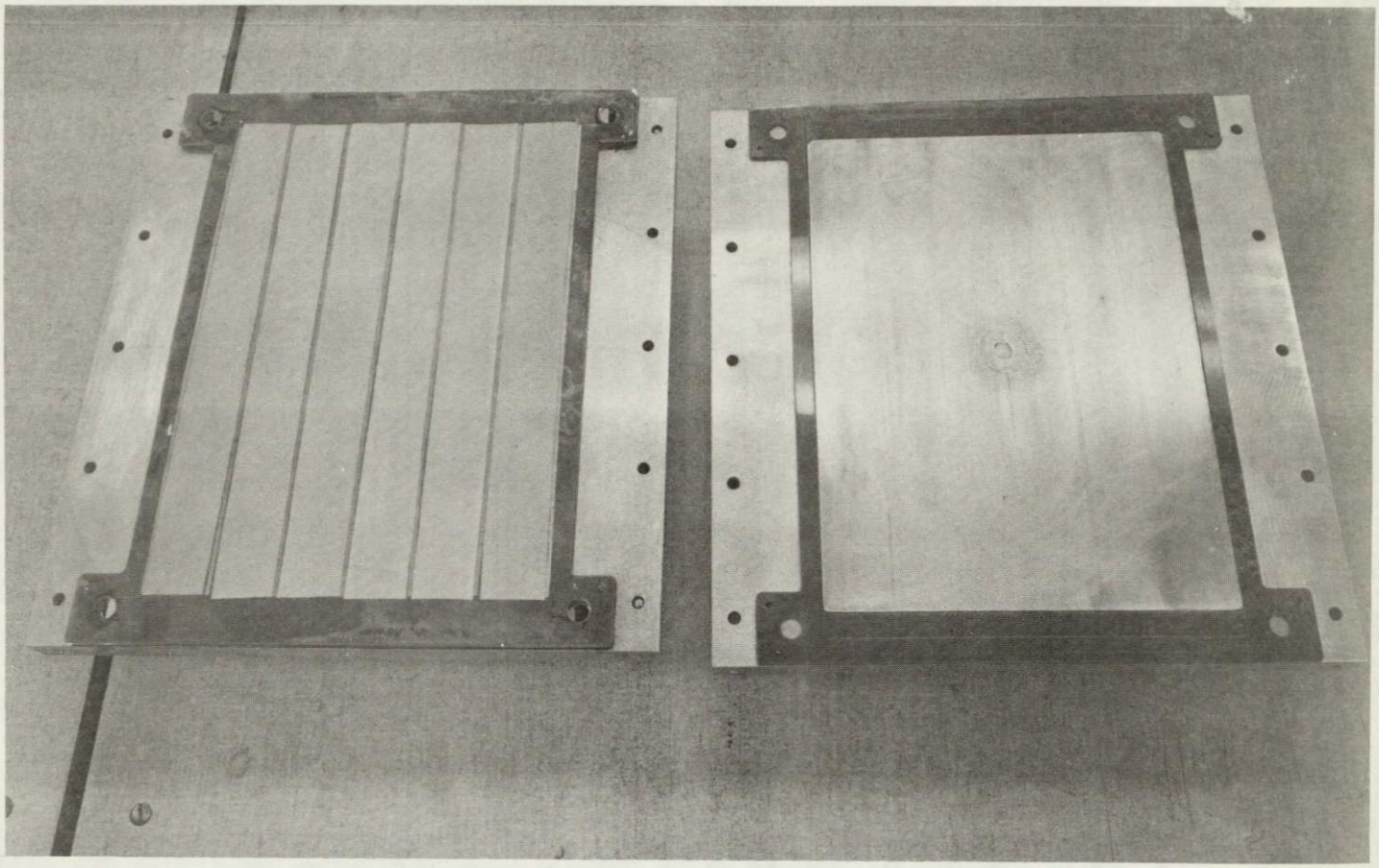

Figure 46. End Plate NT-13 (with Cell Assembly)

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4.0 CONCLUSIONS

The conclusions reached during this PHASE I/IA technology program can be summarized by categorizing the various areas of investigation into one of the following groups:

- Demonstrated advances - items which resulted in an improvement without any detectable detrimental effects.
- Promising areas - items which showed some limited success with the promise of further advances.
- Potential areas - items which were unsuccessfully demonstrated but are still considered candidates for further advances.
- Low probability areas - items which were unsuccessfully demonstrated and which are considered unlikely to be advanced in the near term.

4.1 Demonstrated Advances

4.1.1 Fuel Cell Operation on Contaminated Fuel

Operation of the fuel cell on low purity fuel (33%) was demonstrated with the performance showing only a slight reduction that can be associated with the low partial pressure of the fuel.

With the special anode alloy catalyst, carbon monoxide in the 10 ppm range in the fuel has no initial nor detectable long term impact on the fuel cell output.

Substantial improvement in cell performance on fuel containing in the range of 0.3% carbon monoxide was observed in fuel cells containing the special anode catalyst. Although at this level of CO there is a slight performance decay with time it is completely recoverable with a short term operation on pure hydrogen.

4.1.2 Thinner Low Resistance Electrolyte

The successful demonstration of the thinner electrolyte of the same chemistry as the baseline has a two fold advantage. First the material itself is less costly (i.e. $\sim$25% reduction) and second the fuel cell efficiency is increased due to its lower internal resistance. This results in approximately a 2% increase in initial efficiency at 200 per ft^2 (2.1 amps per cm^2).

4.1.3 Elimination of Anode Distribution Screens

Although the replacement of the anode distribution screen assembly with the embossed niobium plate was not successfully demonstrated with a combination of highly dilute fuel and the thinner electrolyte, it was successfully demonstrated in all other attempted combinations. (i.e. thin electrolyte and pure reactants - standard electrolyte and contaminated as well as pure reactants) In addition to the minor weight reduction ($\sim$ 0.05 lb/ft^2) ($\sim$ 24 mg/cm^2), a cost reduction of approximately \$25/ft^2 (2.7 cents/cm^2) is estimated for a modest production run.

4.1.4 Low Cost Cathode Wetproofing

The demonstration of the commercially available Chemplast material as a suitable replacement for the GE/DECP produced wet proofing material has as its major advantage a greatly reduced cost. Again for a modest production run a cost savings of approximately \$33/ft^2 (3.5 cents/cm^2) is estimated.

4.1.5 Low Cost Cathode

The bipolar current collector technique, which was recently revitalized during the NASA Lewis Research Center Advanced Fuel Cell Development Program, was continued during this program. This technique allowed the changing of the cathode screen from gold to niobium with an insignificant reduction in performance of the fuel cell. This improvement reduces the cost of the hardware by approximately \$95/ft^2 (10.2 cents/cm^2) regardless of the production run size.

4.1.6 Simplified Polymer Processing

The elimination of the polymer platinizing process was demonstrated thru 1500 hours of 165°F (74°F) operation on 16 psia (110 kN/m^2) air and H_2 by not indicating degradation elements in the product water. For a modest product run a cost reduction of approximately \$10/ft^2 (1.0 cents/cm^2) will result.

4.2 Promising Areas

4.2.1 Low Cost Electrolyte

The grafted RAI Polymer, even though that technology is in its infancy, resulted in performance levels only slightly below the baseline configuration. It is expected that with additional development this technology can be a highly reliable high performance fuel cell candidate material.

The one major advantage of this material is its greatly reduced production cost potential. This is presently estimated to be about one quarter the cost of the present standard electrolyte.

4.2.2 High Temperature Operation

High temperature operation was analyzed to have many system advantages. These advantages range from reduced heat rejection systems to a useful by product steam. A baseline cell has operated 800 hours at 300°F (149°C) without cell materials degradation. This was accomplished as part of the IR and D program. Framing and gasket materials presently in use do however degrade in this temperature range. High temperature framing and gasket materials are presently under development in the IR and D program.

4.3 Potential Areas for Advancement

4.3.1 High Acid Content Electrolyte

Although the attempts to fabricate and operate a high acid content electrolyte were unsuccessfuly, this approach appears worthy of additional investigation due to the substantial performance improvement that is inherent in this concept. (i.e. estimated 2% efficiency increase @ 200 amps for ft^2) .21 amps for cm^2).

4.3.2 Weight Reduction in Catalyst Noble Metal

Significant reductions in the amount of platinum in the fuel cell catalysts were not successfully demonstrated without a substantial reduction in output performance. Limited previous experience and the literature strongly supports the contention that considerable more platinum is presently used than is needed for the electrochemical reactions. It is estimated that as much as $\$50/ft^2$ (5.4 cents/cm^2 reduction in costs could be realized with a successful demonstration of the platinum reducti

4.3.3 High Porosity Wet Proofing

Although the attempt at operating a cell with a thin high porosity wet proofing was unsuccessful it still appears like a configuration with a potential for improving cell performance. The increased porosity should result in an increase of oxygen partial pressure at the catalyst/electrolyte interface. This is especially true when operating the cathode with a contaminated oxidant. As much as a 1% efficiency increase could be achieved with this material.

4.3.4 Reduced Cost Separator Materials

The effort during this program was directed toward separator geometric configuration as opposed to modification of the materials themselves. Here again, limited past experience and the literature strongly suggests great strides can be made in this area. A cost reduction of $\$20/ft^2$ (2.1 cents/cm^2) would not be unrealistic with the successful demonstration of carbon or carbon filled separators.

4.4 Low Probability Areas

4.4.1 Improved Cathode Catalyst

No performance improvement was indicated in any of the configurations attempted in this program. In addition, the literature suggests a very low probability that an improved acid fuel cell cathode catalyst would be identified and/or developed in the near term future. It would appear that research efforts would be more profitably spent in other areas at this time.

4.4.2 Conductive Wet Proofing

Although a conductive wetproofing was successfully fabricated, the additional cost of labor and materials combined with a lower overall cell performance indicated that any advantages of this configuration were out weighed by the disadvantages. As in the case of the cathode catalyst investigation, this activity appears to be a long way from paying any dividend and thus should be at least temporarily discontinued.

5.0 RECOMMENDATIONS

The recommendations for the near term technology advancement activities include continued laboratory testing of new concepts and new configurations and a test evaluation of full scale stack NT-1. Figure 47 displays the schedule for the recommended NASA/JSC Technology Program - Phase II. Details of the recommended program are as follows:

5.1 Laboratory Evaluations

The subtasks herein will all be directed toward one or more of the following objectives without sacrificing demonstration life:

- Reduced fuel cell cost.
- Reduced fuel cell weight.
- Increased fuel cell efficiency.
- Improved interfaces (heat rejection)

5.1.1 Increased Operating Temperature

Increased operating temperature will increase fuel cell efficiency, reduce capital costs and reduce the heat rejection equipment required.

The projections made from cell tests at 300°F (149°C) conducted in 1968 and the resistance data of the lowest resistance 5 mil (.1270 mm) membrane extrapolated to 300°F give performance of .84 volt at 300 ASF(.32 amps/cm^2) or 252 watts per square foot(.27 watts/cm^2). The peak power point occurs beyond 1500 ASF(1.61 amps/cm^2) This kind of power density is important in achieving low capital cost, but equally important low fuel consumption as well. The particular cell tested was shutdown after 800 hours for what is believed to be a gasket failure. It was run without humidification of the hydrogen and showed typical distress in the hydrogen inlet area resulting from dry fuel gas. There did not seem to be any degradation in the cell active area except at the inlet during the 800 hour run.

MILESTONE CHART

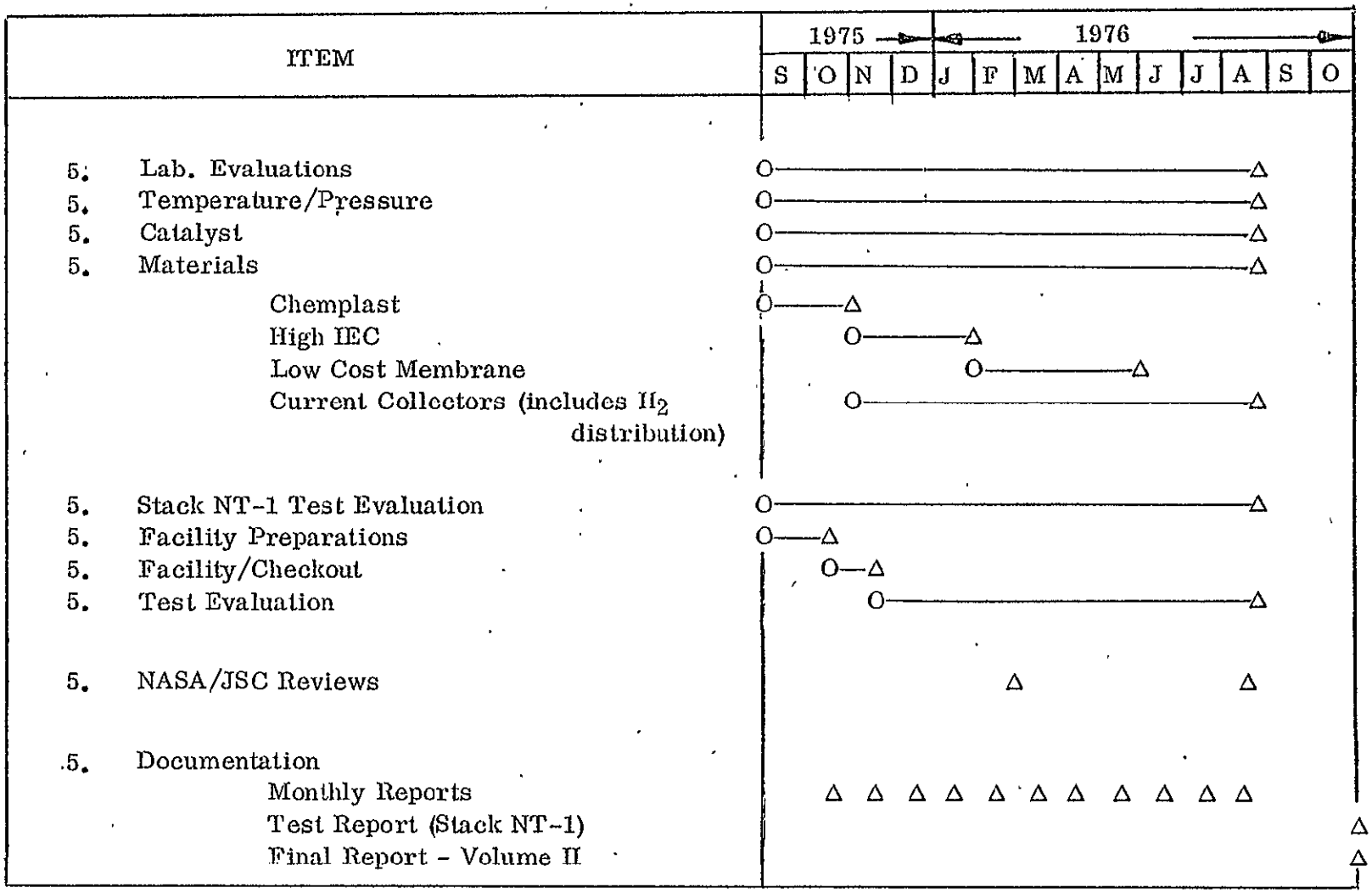

Figure 47. NASA/JSC Technology Program Phase II

Two avenues of approach are open for running the SPE at high temperature. Because of the high vapor pressure over the electrolyte, the cell must be run at a pressure somewhat above the vapor pressure of steam at the corresponding cell temperature. This may be accomplished by running with oxygen at pressure or by compressed air. Running with compressed air involves a compressor, combustor, expander combination which might well be powered by the purge gas from the hydrogen compartment of the cell.

In this subtask the high pressure - high temperature evaluations performed on a 10 mil (.2540 mm) thick electrolyte cell during the Phase 1A technology effort will be continued. These evaluations will include operation of the cell on high pressure air as well as pure oxygen as the oxidant and a wider variation in the contamination levels in the fuel gas. Operation of the cell in the 300°F (149°C) and above temperature range will be evaluated.

One or more additional cells will be fabricated and evaluated at the higher temperatures and pressures utilizing O_2 and Air as the oxident and H_2 and various contaminated fuels as the fuel supply.

Following the parametric testing of the above cells, one will be selected for endurance testing. This testing will then be conducted thru the end of the Phase II.

5.1.2 Catalyst Loading Reductions

At the high power densities to be achieved from high temperature operating, current loadings of 4 grams per square foot (4.3 mg/cm^2) do not appreciably effect the cost of fuel cells. However, platinum is in limited supply and at these loadings, if a sizeable amount of power is ever generated by fuel cells, there would be a major effect on the free world's supply.

In this subtask a repeat of the test performed in 1964 which resulted in a catalyst loading of 0.16 mg/cm^2 and normal performance will be accomplished. Once that performance has been reproduced, a step-by-step transfer of the technology from the liquid electrolyte to the solid polymer electrolyte will be performed.

5.1.3 Materials Evaluations

It is the purpose of this subtask to evaluate materials that can potentially reduce the overall cost or increase performance of the fuel cell.

As mentioned in Paragraph 3.1.10, the use of thin Chemplast wetproofing resulted in good O_2/H_2 performance and poor Air/H_2 performance. This result was not expected and requires additional effort to obtain an understanding of the mechanisms occurring. Testing will be performed with various degrees of cathode side reactant prehumidification. It is considered possible that the initial testing on air was performed at a non-optimum reactant humidity.

In Paragraph 3.1.2, the attempt to operate a high IEC polymer is described. In this attempt, the cell developed leakages before operation was possible. Under this subtask another high IEC cell will be fabricated and evaluated. In order to obtain additional polymer support, the anode configuration will be modified to either a finer mesh current collection screen or a porous metal plate.

In the earlier phase of the technology program, a second source of polymer was evaluated. (Described in Paragraph 3.1.2.) This second source of polymer is manufactured by Radiation Applications Industries Research Corporation (RAI) and it is fabricated by grafting $\alpha\beta\beta$-trifluorostyrene to FEP. This RAI material was found to be equivalent to the standard duPont Nafion (R) at low current densities, but not at good at increased current densities. Continued development by RAI has indicated that improvements in the material have evolved. As part of this subtask a cell from a new batch of RAI polymer will be fabricated and evaluated.

The current baseline cell design uses niobium sheet metal and a cathode screen. In equivalent thickness niobium costs 4 times as much as titanium. Titanium is used on the General Electric/DECP oxygen concentrator project, both on the anode and cathode without problems, but has shown to be subject to long term embrittlement in a hydrogen environment. A possible alternate for the anode is Zirconium, which from early results appears satisfactory as a material for the anode, but costs twice as much as titanium. In 1968 DECP did some preliminary work with graphite for current collectors. It is likely that an impregnated carbon structure could be used for all cell hardware including current collection screens. The effort in this subtask will consist of evaluation of those materials giving a cost per square foot equivalent to .0015 inch (.0381 mm) titanium or better for cell structure and current collection hardware. In addition, the fuel distribution problem in conjunction with 5 mil (.1270 mm) polymer and contaminated fuel (mentioned in Paragraph 3.1.6) will be considered in any material configuration modification. Samples will be evaluated in the 3" x 3" hardware.

5.2 Stack NF-1 Test Evaluation

The purpose of this task is to conduct a thorough performance analysis on the single cell stack fabricated during Phase 1. The objective of the Phase 1 activity was to design and fabricate a scaled up low cost, low weight cell configuration with capability of operation with air or oxygen as the source of oxidant and hydrogen or contaminated hydrogen as the fuel. This cell assembly has an active area of 0.7 Ft^2 (650 cm^2).

The following subtasks will be performed to accomplish the evaluation:

5.2.1 Facility Preparation

Facility preparation will be performed and will include:

- Oxidant and fuel prehumidification controls.
- Pressure, temperature and flow controls for oxidant, fuel and coolant.
- Variable load bank.
- Continuous recording of temperatures.
- Continuous recording of voltage and current.
- Controls for steady state automatic operation with safety shutdowns.

5.2.2 Facility Checkout

The facility will undergo a complete checkout prior to installation of the 0.7 Ft^2 (650 cm^2) cell assembly. These checks will include:

- Reactant humidification operation.
- Subsystem leakage checks.
- Flow and pressure control checks.
- Electrical subsystem operation and checkout.

Following the facility checkout, the fuel cell unit will be installed in the facility. Flow, leakage and electrical checks of the facility/unit integration will be performed.

5.2.3 Test Evaluation

Once the checkouts are complete, a series of parametric tests will be performed. These tests will be performed with pure oxygen and air as the oxidant and pure hydrogen and simulated reformate as the fuel. Operational test temperatures will be 120°F (49°C) and 165°F (74°C). Flow rates of air will be 2.5 and 4.0 times stoichiometric flow, whereas contaminated fuel flow will be 1.25 and 1.50 times stoichiometric flow.

An endurance test will be performed following the parametric tests. It is planned to operate on air as the oxidant and contaminated fuel. Once per week a complete polarization will be performed and a minimum of one load change per working day will be made. A complete test log will be maintained throughout the test program.